# A METHODOLOGY FOR FINE ART FORMULATION APPLIED TO INVESTMENT CASTING MOULDS

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## Abstract

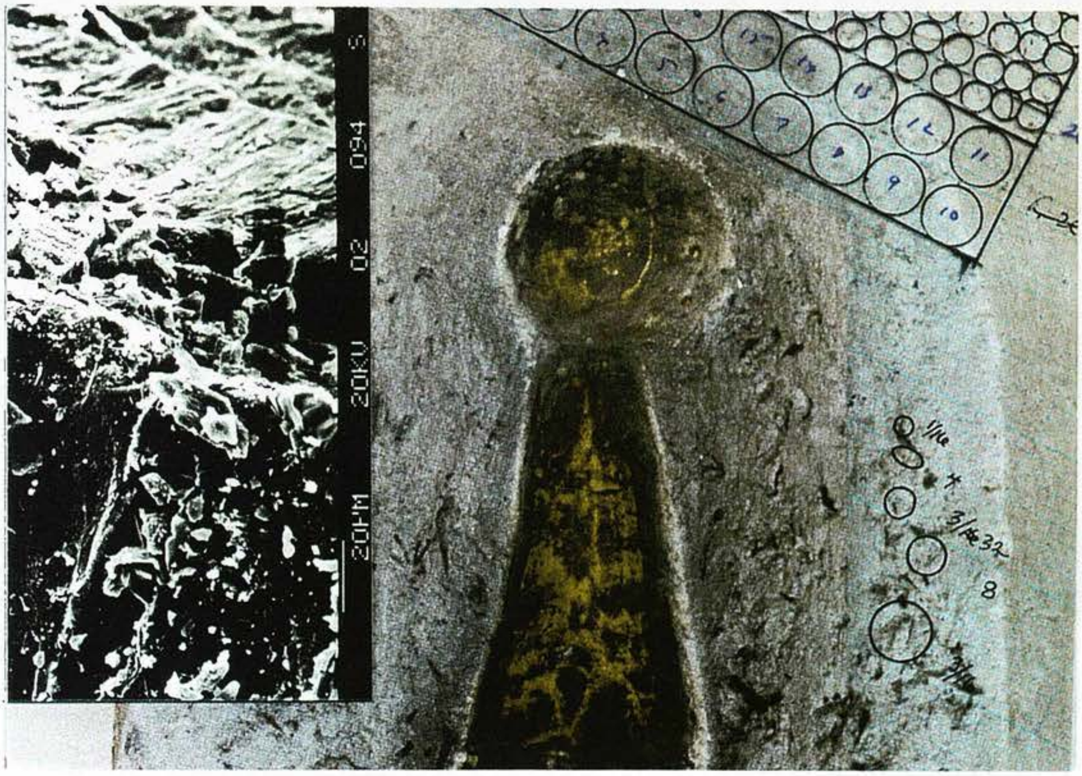
This research concerns the development of a methodology for formulation in Fine Art, Design and Craft practice. The methodology is applied to the choosing of formulations for bronze and glass investments casting moulds in which a significant ingredient is cuttlefish bone powder, but it is claimed to have an applicability beyond this particular example.

The methodology involves four steps;

- identifying key attributes (effects) which the required formulation must display,
- identifying the roles, shapes and sizes of the components of the formulation,
- finding a model which combines the component characteristics into a visualisation of the formulation, referred to as a "microstructure drawing", and
- using the microstructure drawing to describe the behaviour of the formulation.

The research approach taken is to search for a suitable set of formulations using a traditional trial-and-error process. The key attributes required of the formulation are defined in terms of the handling characteristics, and the mechanical integrity of the hardened mould. The components are then characterised using micrographic images and a set of symbols developed to represent their size, shape and function. Then a visualisation of the formulation is developed by mixing symbols in proportion to the amount used in the formulation. These microstructure drawings are then used to describe the behaviour of the formulation.

Conclusions are drawn as to the value of the microstructure drawing as an additional "sense" which the practitioner can use when searching for a suitable formulation. Comments are made on the generic aspects of the work, the feasibility of using cuttlefish bone powder for investment casting moulds, and on the communicability of the methodology.




**Invitation card for author's exhibition at Edinburgh College of Art (6-26 August 2000)**

# Chapter 1. INTRODUCTION AND THESIS OUTLINE

## 1.1 Introduction

The focus of this research is the development of a methodology for Fine Art, Design and Craft practice which is both clearly communicated (and communicable) to practitioners within these disciplines, whilst being auditable as an approach which will find a solution for the particular problem in hand.

The general methodology is concerned with the choosing of formulations in relation to achieving specific effects, such as mechanical properties or textures. The specific case to which the methodology is applied is the formulation of investment casting moulds for glass and bronze sculptures, where the significant ingredient within each formulation is cuttlefish bone powder and the required effects include the handling of wet mix (slurry technique) and the behaviour of the resulting mould during the investment casting process.

The research is not incremental insofar as it does not implement an established methodology to add to the base of knowledge and understanding in the way that scientific and engineering research has developed. Indeed the research is more about methodology, in that it develops a kind of intuitive and experiential approach to technological processes within fine art practice. This points to a clear distinction between the artist who engages technology as part of the creative process and for whom there are few reliable processes, and the scientist/technologist for whom there are established and auditable methods.

The literature review will therefore locate the research from two positions; one contemporary and the other historical, the latter in acknowledgement of the fact that there was a time when the aforementioned distinction was less clear and that the approaches used for production and one-off fabrication diverged around the time of the industrial revolution. It could be said that the modern engineer has delegated the process of production to machines, whereas the direct engagement of the artist in production is a key element in the creative process.

The two streams of the literature review are therefore focused on:

- the current ways in which process is communicated within the Visual Arts, usually through word–of–mouth descriptions of trial–and–error procedures as described by Cummings (1997) and Feinberg (1994), and,
- the historical point at which industrial mass production, normally associated with industry, diverged from individual methods of producing bespoke products, currently associated with Fine Art and Craft.

Reference will therefore be made to early mechanical engineering sources, as well as sources on industrial archaeology. Modern engineering sources will be cited, but only to illustrate the depth of the gulf between craft and production engineering related to casting.

At no point does this research employ or propose strict experimental methods, equivalent to those of Materials Engineering. Rather, the research proposes more reliable and reproducible methods (than those currently available) for Fine Art, Design and Craft practice by providing clear, transferable knowledge about the use of cuttlefish bone powder in investment casting. Central to the methodology is a model which allows the practitioner to picture the formulation and its behaviour, and hence interpolate the experimental process undertaken, itself an extended form of trial and error.

Crudely put, the practitioner is given an additional "sense" (which is, in effect, a model of the material) which, in a scientific context, would comprise a set of experimental measurements. The analysis of the results (use of the model to interpret the relationship between formulation and effect) again mirrors, but does not employ scientific technique.

The result is a methodology, which can be applied by a practitioner not versed in science, but which is valid for the purposes of fine art practice.

### 1.2 Thesis outline

The thesis is organised in nine chapters, including the current one.

Chapter 2 contains the literature review in which the argument for pushing the boundaries of the craft / fine art process is located into two areas:

i. By evaluating the ways in which craft / fine art processes are and have been communicated:

- that, for the practitioner, knowledge of process is gained by a combination of word of mouth, trial and error and (in the West) through sculpture manuals
- that the process itself has remained very stable with few developments of a technological nature
- that no-one has visualised how the ingredients work within the process as a way of extending intuitive control.

ii. By tracing the point at which engineering diverged from craft / fine art practice in the 19th Century:

- that there has been a divergence between engineering practice and craft to the extent that the methods of engineering now are totally inaccessible to practitioners
- that there has been a divergence in production and fabrication methods; engineering towards quality control, craft and areas of fine art towards greater human contact within the production process, a more intuitive control
- that the focus (to a large extent) in fine art and craft is on one-off artifacts, whereas that in engineering has laid more emphasis on reproducibility and mass production

In general, it is concluded:

- that there is a need within practice-based disciplines (such as fine art/ craft /surgery) for understanding procedures through 'doing', through direct experience of practice and intuitive handling, rather than through theory alone. Some theory is required to back up experience but it needs to be comprehensible to practitioners

- that there is a need to develop a methodology which allows practitioners to both understand process, so that it can be used intuitively, and to communicate the process so that it can evolve to greater efficiency without losing the intuitive element

Chapter 3 describes the cultural context of the research, principally to whom it is directed. The local culture context in Malaysia (explored as part of the process of acquiring the material) has dictated the particular choice of material studied, but there is a generic element to the methodology developed that addresses other practitioners of Fine Art and Craft, both with regard to the formulation of sculpture moulds and to formulation more generally. The key findings in the context of utilisation of a natural waste material are:

- carved whole cuttlefish bone is currently used in the casting of jewellery, but castings made in this way are limited in size and versatility
- cuttlefish bone powder is obtainable by careful selection of sources of the bone itself and control and supervision of the crushing process
- there are no known formulations for the use of the cuttlefish bone powder as an ingredient in investment casting moulds

Therefore there is a need to develop formulations for investment casting which are reliable, and in which cuttlefish bone powder is a significant ingredient. It was decided to approach this problem in two stages:

i. The development of a slurry technique that fulfils stated criteria.

ii. The testing of a selected number of moulds for mechanical integrity and heat resistance during the investment casting processes for both bronze and glass.

Chapter 4 describes the experiments which were carried out to examine the handling and setting characteristics of various formulations (the slurry technique). The objective of the experimental process at this stage was to arrive at an acceptable match to a set of practical criteria, using formulations with a significant proportion of cuttlefish bone powder in place of conventional refractory materials. The starting point of the experiments was semi-arbitrary, given that there is no established knowledge base in this area from the perspective of fine art and craft practice. The experiments were conducted in the way in which a practitioner would approach the problem, and the quantity of water and the type and quantity of dry ingredients were varied in a trial and error fashion. Two series of experiments were carried out, respectively, for bronze casting moulds and for glass casting moulds.

On the basis of this set of experiments, a subset of bronze and glass formulations was selected for further testing, for heat resistance and structural integrity.

Chapter 5 deals with the experiments related to the integrity of the moulds selected for further testing. Again, the approach was much as it would be for a practitioner in that the moulds were subjected to the processes of firing and filling, and observations were made of the quality of the finished piece and the durability of the mould itself.

Chapter 6 deals with microstructure drawing as a technique for visualising the structure (and hence the behaviour) of the wet mix and the set mould. Because of the semi-arbitrary starting point of the experiments, and the trial and error approach, it is impossible to prove that the formulations are, in fact, optimum. It is important to be able to revisit the experiments to try to understand what is happening within the material in the process of developing the mould, and then investing the mould. There is a need, therefore, to understand not only ***that*** something works, but also ***how*** it works, sufficiently and with limited scientific knowledge.

The way chosen to address this need was to develop a visualisation or model of the material which is understandable to and usable by other practitioners, to whom the research is directed. Therefore it is an intuitive rather than scientific model, a tool for practitioners who are non scientists, a tool that more closely resembles the drawings of early engineers, eg Bagshaw (1891), than current engineering mathematical models, eg Liu et al (2000), a tool which extends the understanding of craft practice beyond contemporary explanations of process, eg Mills (1995) and historical explanations within fine art / craft, eg Cellini, in Leoni (1979).

The elements of the model (based on microscopical images of the components and hardened moulds) include the representation of particles both in shape and relative size, water, and interlocking branches depicting the hydration process.

Chapter 7 uses the model to analyse the experiments, comparing the images with the original records of the test results, initially by taking the best and the worst moulds.

Both the representation and the original test results are critically evaluated, as it cannot be assumed that either is correct. The original criteria of evaluation set out in Chapters 4 and 5 are brought into this analysis.

Chapter 8 contains a discussion of the value of the process which has been developed. Three important points discussed in this chapter are as follows:

- an internal criticism of the method undertaken.
- an external criticism, identifying any outstanding research to be done.
- an evaluation of how the research builds on current knowledge, or is better than current knowledge.

Chapter 9 contains the conclusions of the research the most significant points of which are as follows:

- there is merit in using the waste material, cuttlefish bone powder, in a moulding process for bronze and glass casting
- in the process of researching how this waste material can be used, a methodology has been developed for formulating the resulting process
- the methodology has been used in a critical way, in that the 'extended trial and error process' has been revisited to see what might be improved
- some insight has been gained into the divergence of motives between the communication of process for engineering and for fine art practice

It is suggested that craft / fine art seeks effects for the purposes of expression, whereas engineering seeks reliability (in the sense that what is designed is what is produced), and requires technology for purposes of replication. It is argued that extending the way in which process in craft and fine art practice is currently communicated, leads to greater reliability of the generation of effects, and hence more intuitive control for the practitioners.

# Chapter 2. LITERATURE REVIEW

## 2.1 Introduction

The purpose of this chapter is to position the research from two perspectives:

i. by evaluating ways in which craft / fine art process are and have been communicated within the disciplines. The research seeks to develop a methodology which is reliable, auditable, communicable and intuitive in relationship to investment casting procedures for practicing artists and crafts people

- by reliable we mean that we can be sure about the method / process
- by auditable we mean that it should be possible to reproduce the process
- by communicable we mean that it should be possible to explain and share the information on the process clearly
- by intuitive we mean that it should be easy to use, understand and have a feel for the process / method without any special education or training

This aspect of the literature review demonstrates that current methods of communication do not fulfil all four criteria taken as a whole.

ii. by tracing the point at which engineering diverged from craft / fine art practice in the $19^{th}$ century. Whereas methods of engineering practice do fulfil the criteria of reliability and auditability, they are now, in many cases, inaccessible to practitioners, ie they are neither communicable nor intuitive. There has been a change in production and fabrication methods in engineering, towards quality control and automated manufacture. In craft, and areas of fine art, there has been a move towards greater human contact within the production process, a more intuitive control, which is important to retain in expressive practice designed for use by artists and crafts people.

## 2.2 Communication of fine art and craft processes

To the artist or craft person, the process of moulding follows the main activity of creating the artwork. Foundry people are tied to tradition with little time for research. This creates an immediate distinction from the engineer whose principal problem is the process of replication itself, and the issues of reliability and precision implicit in its development and communication. Therefore the quality and type of information as well as the method of communication sought by a sculptor, craftsperson or foundryman will be different from that of the engineer in crucial ways.

Books and written material relating to casting methods reveal the fact that there is a great deal of understanding about the basics of metal and glass casting that is transferred from person to person and era to era by word of mouth. Often this comprehension about the methods varies from person to person and era to era because conditions change, materials available in one situation may not be around in another and some individuals may have different intentions for the process. Fine art casting remains an industry of small businesses, in fact often the artist himself being the founder too. Each casting has to be considered as a new set of problems, because each new work is absolutely different in form, scale, texture etc. to the ones before e.g. the runners and risers are designed in response to the specific shape and surface quality of the piece. These factors give rise to a huge number of process variables.

Information about the communication of fine art and craft processes analyzed in this review, has been drawn from two main sources: a selection of sculpture / craft manuals and interviews with a small selection of practitioners in Scotland and in Malaysia. In neither case is the research exhaustive, but sufficient to determine to what degree information about the material processes, particularly those of investment casting, are communicable, auditable, reliable and intuitive. Current methods of communication are examined through a few key texts, to include Mills (1995), Thomas (1995) and Williams (1995). Interviews were undertaken at the outset of the research in both Scotland and Malaysia to cross-reference with the manuals on how individual craft and art practitioners and foundry persons gain knowledge of process and if they had ever used cuttlefish bone in the manner proposed by the research.

### *2.2.1 Sculpture and craft manuals: contemporary*

What can be observed from the sculpture manuals is that the whole process of investment casting is told like a story, which begins with the clay original, the reproduction of this into wax and the replacing of the wax into bronze. Significant milestones in this process are:

- the slurry technique stage
- the investing of the wax
- the burning out of the wax.

In three key texts the slurry technique stage is not handled in any great detail. In Mills (1995) a formulation is expressed in terms of proportions of materials, with intuitive measures of how these proportions should work ."The mixture, two parts

Ludo, one part fresh grog and one part plaster, should be mixed with water to the consistency of thin porridge." (p.46).

Thomas (1995) gives no proportion of materials but echoes Mills' intuitive control, the first coat "consists of a mixture of Herculite plaster.... and fine grog". The second coat is "a mixture of normal plaster and a material called 'Luto' This investment mixture is mixed to a porridge consistency." (p.97-98). Williams (1995), like Mills, offers a method of proportioning the materials (this time to include water) i.e. equal proportions of water and plaster followed by equal proportions of plaster and masonry sand for the first coat. He suggests one-third sand to one-third plaster to one third Zonolite, "a refractory often found in garden nurseries" for the second coat. He also suggests that "the investment mixture must be mixed properly to withstand the high heat of the bronze" (p.181). He does not however expand on what a proper mixture should be, nor why this might improve heat resistance.

It is useful to the sculptor to have the materials expressed as proportions as this allows for the flexibility to calculate different quantities depending on size and surface quality of the pieces of work. However, crucial information on the proportion of water to dry ingredients is missing from both Mills and Thomas. The intuitive measures that both these writers give for judging a good mix are very culturally specific. Porridge is not a good reference for Malaysia, nor is Zonolite a known material outside America.

This inconsistency and lack of detail is carried over into the development of the investment mould around the wax. The most comprehensive information is supplied by Mills, who gives a number of basic requirements for moulds to withstand the various pressures at the pouring stage of the process. These requirements are expressed in terms of a set of parameters against which judgments should be made e.g. judging the thickness of the mould. A thicker mould would be required when it would be likely to be subjected to fluctuating heat, a heat source which is not constant. The outer shell of the mould may become very crumbly but the inside will be protected provided it is not subjected to excessive heat for too long. Another example is the consideration of shape. A small section can be close to the surface in a shape whose contours are varied. However, a consistently wide area such as a panel requires a greater thickness of mould. Finally Mills anticipates the pressure of the liquid bronze, which increases with the height of the mould, by recommending that the bottom of the mould be strengthened in proportion to its height. All these suggestions function towards keeping in mind the whole event of the casting, and the rapid flushing of metal through the mould.

In contrast, Thomas (1995) leaves us no image of the event and its impact on the investment mould. There is a single reference to the strengthening of the mould by using chicken wire. Williams (1995) echoes the need for chicken wire and also specifies that the mould should be built up to a thickness of 1.5 inches, without introducing any flexibility in response to shape. Later, there is a step by step description of procedure, without the articulation of opportunities for making judgements provided by Mills.

In terms of the burning out of the wax, Williams is full of dangerous inaccuracies. He recommends burning the wax out at 1500 degrees. "The temperature is raised until the 1400 degree cone is down" (p.183-4). Normal practice, confirmed by both Mills and Williams, recommends 650°C for burn out. Even allowing for the possibility that Williams is dealing in Farenheit degrees, the great temperature recommended by Williams would almost certainly weaken the mould disastrously. On page 184 he also suggests that there should be no flames from the moulds at the burn out stage, whereas in fact wax burns at 600-650°C. Others (e.g. Thomas) use the dying out of these flames as an indication that all the residues of wax are gone. Thomas (page 99) recommends bringing the temperature of the kiln to 400°C then 650°C at which point the moulds will flame 'for several hours'. This flaming is an indication that "carbon is still left in the mould". Mills gives an indication of the time involved in burn out by suggesting that a kiln full of moulds equivalent to life-size heads will take about 18 hours of firing. He covers a number of eventualities by describing the differences between a pottery kiln and a mould kiln, anticipating the different working environments that a sculptor might find himself in.

This comparison points to a variety of approaches within the narrative or story telling of the processes - that there are great differences in terms of accuracy (such as leaving out crucial information about water within the slurry technique stage), that some of the information is wildly unreliable (Williams' temperatures and description of the burn out stage) and that some types of information are more useful than others to the practitioner e.g. Mills describes stages of the process by keeping to the forefront the whole event, its requirements and its variations allowing the sculptor some room to make judgements and to work within a set of principles, a primitive form of auditability. This is in contrast to the other two whose descriptions are largely tied to specifics.

Williams, Thomas and Mills are broadly from the same historical period (1960-90s) and make full use of clear photography to illustrate stages of the process as it is actually being done, providing the reader with some means to anticipate what they are aiming for. Mills backs up the actual event with clear diagrams that visualise the process described in words, thus providing another significant opportunity to access the process. The diagrams produced by Williams (p.182) and Thomas (p.96) with the process description show only the cross-section of the wax model and gate system within the investment casting mould, and do not show the slurry technique nor the investment process. Nevertheless, this diagrammatic method of visualising process has provided an important methodology within the research.

Whereas in some (though not all) cases the information could be described as reliable, communicable, and intuitive it is rarely consistently so. Auditability is hinted at in Mills but is not an issue in either Thomas or Williams. These three examples could be described as being representative in different ways of the general approach to be found within the discipline in the latter half of the twentieth century. (Feinberg (1994), Hauser (1974), Munro (1986)).

### *2.2.2 Sculpture and craft manuals: historical*

In his article on the techniques of casting (Leoni in Wilton- Ely 1979), Leoni opens with a clear statement on the lack of change in casting processes

"Without any doubt the casting of works of art is the metallurgical technique that has changed least throughout the centuries." (p.171)

He describes wide ranging sources of information about casting to include 5th Century BC vases (Fig. 1), such as the Kylix of Vulci, Cellini's Treatise on Bronze as well as his autobiography, the descriptions by Boffrand in 1743 of the casting of the equestrian figure of Louis XIV (Fig. 2) through to contemporary methods using silicone rubbers and refractory oxides in the moulding process.

According to Leoni, Benvenuto Cellini's "Treatise on Sculpture", written in Italy in the 16th Century was one of the first books on casting processes. It contains observations on many technical practices involved in making sculpture. Consequently the text which refers specifically to the subject of investment moulding is relatively small within a broader subject matter.

Commentators on this book make a number of common points. The information is carried primarily within a story about the vicissitudes of life encountered by the sculptor. When there are detailed comments on the mixes for moulding materials these refer to typical ingredients, which are mostly understood to function in the desired way but are offered as to "be mixed according to artist *whim*". The individual ingredients, horse dung, urine, burnt horns of rams are unlikely to be easily available today or suitable for use in contemporary conditions. Using these materials Leoni notes that long preparation time is required by leaving the mix for a long time to become "an easily worked medium". Such commentaries reflect the excitement generated by fine art casting. Large monuments take many months to make, perhaps even years and casting at the end of such a long period builds a tension, and worry as to the outcome. This understandably results in an unusual working atmosphere of adventure, creativity and risk as it remains to this day.

Although the process itself has remained stable, contemporary attempts to record the "cire perdue" casting process have progressed in terms of their ability to communicate the process. Photographic reproduction has improved the ability of authors to record the stages of the process. There is greater consistency in detail regarding material, and more definite guidance on the proportion of ingredients in the various mixes, where in the 16th Century versions there is none. However, most decisions about quantities of refractory to cement remains the personal choice of the writer by feel not by proof.

### *2.2.3 Descriptions of slurry technique for glass*

Descriptions of the slurry technique stage for glass by Schuler (1971), Carder 1971, Bray (1995), van Loo (1995) and Cummings (1997) echo many of the principles to be found in bronze investment casting: expression of proportions, intuitive methods and descriptions of what to expect with some slight variations in the materials used in the process.

## 2.3 Evidence from the interviews.

A number of interviews were undertaken in Scotland and Malaysia at the outset of research to determine the feasibility of the research proposed. Questions included whether cuttlefish bone powder was in use as an ingredient for investment moulding (see Chapter 3). The interviews also determined in very broad terms the level and expertise in relationship to different types of foundry practice of the practitioners (to include fine artists, crafts people and foundry people), the kinds of materials and related processes they were familiar with, and the degree of recyclability of materials from these processes. These interviews are neither exhaustive nor do they purport to represent a significant sample. Although the interviews were conducted early on in the research, i.e. before the specific nature of this literature review was determined, they nonetheless confirm that discussion of the process tends to be very broad based, with emphasis on craft rather than replicable and guaranteed procedure.

In Scotland two semi-structured interviews were undertaken, one with an experienced foundry person and the other with a senior member of staff from Edinburgh College of Art. These interviews confirm that neither of them has used cuttlefish bone as an investment casting mould for bronze and glass sculpture. Furthermore, neither of them provided comprehensive descriptions of process that could be described as reliable, auditable, communicable and intuitive.

Kerry Hammond (interviewed on 16th February 1998) communicated the slurry technique process in simple ways of using the materials without giving an accurate formula or procedure. There are correspondences in the materials used with the previous bronze practitioners sculptor / foundry. These include China clay, collidal silica, traditional grog investment casting mould, fine grog, Herculite, casting plaster, coarse grog and Ludo. The mixture was to be applied layer by layer and the final layer strengthened with fibreglass matting. More importance is given to the craft of building up the layers to produce a strong mould, than to the quantities of materials used. In comparison Iain Davidson (interview 21st January 1998), describes a slightly different type of experience. He is a craft person and he had used cuttlefish bone for direct casting in making rings. (Plate 1).

In Malaysia the way that practitioners communicate the process of investment casting is from one generation to the next generation, by word of mouth. The processes are not written down, making it very difficult for a new generation to follow a reliable process. This is evidenced in the interview with Mr. Omar Mohammad (4th May 1998), who describes using traditional investment casting methods for pouring nickel, copper and aluminum. He uses traditional material such as clay "lumpur", beach sand (fine and coarse), rice husk and straw ash with water, emphasising the building up of layers. Like Kerry Hammond of Powderhall Bronze in Edinburgh, Mr. Omar Mohammed's experience significantly spans 15 years of foundry practice.

Another interview in Malaysia was with Mr. Mohamad Sabri Abdullah (3rd May 1998), a technical executive in investment casting technology in the Standards and Industrial Research Institute of Malaysia ( SIRIM ). Sand mould, block mould and shell mould are the materials usually used in investment casting. The way he communicates the moulding process is by word of mouth and the material that he uses for the investment mould include plaster of Paris and silica powder. There is no standard formulation documented.

## 2.4 Historical development of the investment casting process

Investment casting essentially involves the production of a positive pattern from a low melting point material, surrounding that pattern with a moulding material, and then removing the pattern from the mould by melting it and allowing it to run out, prior to pouring in the final material from which the casting is to be made. The term "investment" refers to the clothing of the original positive in the mould material. Fig. 3 shows the process variants used in this work for bronze and glass casting.

Investment casting appears to have been used as long as casting itself, being traceable as far back as 4000 BC (Bidwell, 1969). Throughout its history, right up to the present day, investment casting has been associated with precision, particularly in the production of jewellery and artistic artefacts, Fig. 4.

There is some evidence (Tylecote, 1962) that Bronze Age man (ca 1200 BC) used low melting point metals (principally lead) as the pattern material for bronze castings. Up until the time of Cellini's bronze of Perseus with the head of Medusa, the use of investment casting remained mostly in the hands of artists. In the mid-sixteenth century, there is an interesting report of the use of the lost wax process to produce the art work on bronze gun barrels (but not the barrels themselves), Bidwell (1969). Despite its use by dentists and jewellers, it was not until the late 1930s, that investment casting became an industrial process, initially for aero-engine parts and later in general engineering, Bidwell (1969). Recently, investment casting has found an important niche as a rapid prototyping technique, because the pattern can be produced by Rapid Prototyping (RP).

Moulding materials for casting have a similar long history, the most ancient having been carved out of stone, Aitchison (1960). Obviously, carved moulds are not suitable for investment casting, and it appears that the earliest investment casting moulds were made from clay, which would need to be dried before removing the pattern or pouring the metal. The clay would crack and craze during drying and this was useful to allow gases to escape providing risers for the poured metal

(Tylecote, 1962). In the Middle Bronze Age, permanent bronze moulds (Fig. 5) were first used in Britain. These appear to have been produced from clay and probably also used clay cores.

According to Tylecote (1962) it seems most likely that these moulds were used to produce investment patterns of lead or wax patterns. Interestingly, he comments that this idea was probably imported from Continental Europe and that Irish founders were beginning to lose their hold on the English market, when "the demand for palstaves and socketed axes became very large". Here we find the first indication of divergence, where the "engineering" requirement for efficient production has an effect on technology.

## 2.5 Communication of process amongst engineers

The communication of technology amongst engineers became a routine matter commencing in the nineteenth century, with the establishment of the engineering institutions and their associated proceedings. By this time, engineers were beginning to become concerned with quality, measured, for example, by the soundness and the strength of the metal. Such things were subject to experiment and the experiments were reported to other engineers in order to promulgate knowledge. For example, in the Proceedings of the American Society of Mechanical Engineers we can read (West 1884-85):

> "A sound casting can seldom be judged by its outward appearance.
> The smooth skin is often nothing but a shell covering defectiveness,
> and not until a casting is broken is its soundness known.........

........Since making the above tests it has occurred to the writer's mind, that his first experiments which showed dull iron to make the strongest bars were affected by the fact of the first test bars being poured with metal which was, as stated, agitated with wrought iron bars"

What is clear here is that the experiments become the property of the entire engineering community. The experiments are reported with a precision which would allow another engineer to reproduce them exactly, and most papers were followed by a recorded discussion forming a critical review of the work. There is a common sense of purpose, based on auditable and communicable procedures, the auditors being the members of the institution, the means of communication being the proceedings and the sense of purpose being the reliable production of sound castings.

However, not all is precisely measured, and engineers at this time might also communicate their experiences in a more subjective way. West (1886-87) says:

> "...in order to produce a sound casting [in aluminium bronze] the core must be 'rotten' and of a yielding character...."

Another example of how engineers have dealt with practice in a production context is given by Bagshaw (1891) in a discussion on the mechanical treatment of moulding sand for the casting of iron. Bagshaw, an iron founder, was interested in the wear of mechanical riddles and had made some drawings (eg Fig. 6) of images of sand particles taken down a microscope to illustrate the effect of crushing, coal dust attachment and recycling of burnt sand on particle size and shape.

The ensuing recorded discussion illustrates the intuitive use that other founders made of the information, for example the comments of a Mr James Platt:

> ".....it was well illustrated by the magnified drawings shown of the materials. Doubtless many engineers would be surprised to see the forms that moulding sand assumed under the microscope; but on consideration it was obvious that the sand must be composed of particles or grains of stone, coal, and other ingredients to make it cohesive or fibrous. The riddle............ got through an astonishing amount of work, and mixed the sand in the right way. The feel of the sand so mixed was very much like that of the sand mixed by treading..."

This is in contrast to the way in which, say, the problem of wear by particles acting on a surface is treated in modern engineering, and the developments have been fuelled by the evolution of engineering science and subsequently by the availability of computing power to solve difficult numerical problems. The "engineering science" approach would attempt to develop models of the wear process and supplement these with observations, Fig. 7.

In more modern tribological theory, the models have become more sophisticated and require more intense computation, Fig. 8.

In the 1920s and later, industry became more and more production oriented and competitive, and even the materials and processes themselves become competitors for the production engineer's attention:

> "The commonest and cheapest of all structural ferrous materials, it [cast iron] has always been metallurgically neglected, and its replacement by competing ferrous and non-ferrous materials in engineering practice appeared formerly to be only a question of time........notably in internal combustion engineering..." Pearce (1925)

Bidwell (1969) refers to the industrial development of investment casting in the 1930s and 1940s, noting that most of the foundries practising investment casting were tied to aircraft companies or were set up to produce aircraft quality castings. This whole development was driven by the extreme difficulty of machining or working the cobalt-base alloys necessary for turbine blades, the complex geometry of these blades, and the need for extreme soundness, accuracy and reproducibility in such applications. Bidwell goes on to state:

> "The [investment casting] industry rapidly moved away from the 'exotic and expensive' label and is competing successfully with other forms of casting ............as well as producing those components which are designed to take maximum advantage of the investment casting process."

## 2.6 Modern process developments

Moulds for investment casting have also developed apace, and the modern process uses either block or shell moulds, which, in either case, are destroyed to remove the final casting. The mould material needs to have appropriate characteristics, which allow it to take the pattern detail and then become stiff and strong enough to withstand the heat and stress of the casting operation, whilst being sufficiently brittle to be removed without damaging the casting. In order to have these characteristics the material has to be introduced as a slurry and then has to dry and harden or set. Moulds are commonly fired before pouring of metal.

The components of a mould can be classified as binders and refractory fillers, a direct analogy being possible with concrete where the binder is mainly cement and the fillers are sand and coarse aggregate. Bidwell (1969) notes that the majority of binders used in industrial mould production are silicates or silica sols, although he does acknowledge the use of phosphates, aluminous cements and plaster of Paris. The process involves the setting of binders including gelation, hydrolysis and, in the case of cements and plaster of Paris, hydration which lead to crystal growth and interlocking of the hydrate crystals. Bidwell notes that the plaster of Paris hydrate ($2CaSO_4.2H_2O$) starts to break down at 750°C and completely dissociates at around 1100°C. Aggregates listed by Bidwell include; silica, alumina, chromic oxide, magnesia, calcined china clay, mullite and fireclay grog. He notes that refractoriness is only one of the required properties in a mould, thermal expansion being also important in terms of dimensional stability and resistance to thermal shock, and, of course, ready availability at an acceptable price. Fillers also need to show consistent chemical and physical properties and be compatible with the materials being cast.

As well as engineering design methods becoming more and more specialist (Fig. 7), the requirements of increased quality and efficiency are also becoming more stringent. For example, as in the case of turbine blades, the wheels of cars now need to show the highest possible reliability and the alloy castings need to be inspected extremely carefully to ensure that there are no internal cavities which might compromise their structural integrity (Fig. 9).

Increased reliability is not the only driver in modern engineering production; there is also a need to make products efficiently, which normally means that processes are automated (de-manned) as much as possible to provide for mass production at an acceptable cost. Fig. 10 shows a typical modern engineering investment casting process as might be used for hip joint prostheses.

In the pursuit of increased efficiency, computer-aided methods are now, for example, used to help design casting patterns. Fig. 11 shows a screen from a computer tool (Park and Lee, 1991) which calculates the most effective pattern for a particular casting, in this case a gear blank.

Another step-change in the efficiency of casting, which makes direct use of investment casting, was brought by the advent of rapid prototyping (RP) technologies. RP exploits a class of manufacturing processes which can produce three-dimensional objects in layers (Fig. 12). Because the manufacture is in layers, it is necessary to "slice" the design and this is usually done using a computer model of the object and applying a "slicing algorithm" to it, Dolenc and Mäkelä (1994). The slices are held in a special type of computer file, which is used by the manufacturing process, this process building up the object from the slice data.

Again, a computer algorithm is required to convert the slice data into a set of instructions which the machine can read to produce the object (Hur et al, 2000).

RP processes are currently limited in the types of materials that can be manufactured, most processes using some type of resin. This normally limits the use to which RP objects can be put and they are most commonly made to visualise a three-dimensional object in a way difficult to do with computer graphics, a "show and tell" model. However, RP techniques can be used to produce the patterns for investment casting moulds, thus saving the need to produce a new pattern for each and every casting. Although there are some technical difficulties in removing RP patterns from the moulds, it looks as if investment casting will be the first move from rapid prototyping to rapid manufacturing (Yan and Gu, 1995)

**2.7 Summary of argument and identification of thesis topic**

The methods and materials used for fine art investment casting have remained remarkably stable over the ages. Rich (1974) has said. "The principles involved are not new, and have been used from Antiquity". Actually, after the very early stone moulds, a certain development of formulation using refractory materials and binders of differing combinations can be seen, and this does suggest some understanding of the requirements for moulds to perform in a satisfactory way. However, since casting was carried out by artists or craftsmen, the process was often seen as means to an end and dependent on good sense rather than accurate information. Some practitioners have been openly critical of the "black art". For example, Feinberg (1994), when specifying his formulations, said. "In practice, the preparation of clay moulds often involves weeks of work, various 'mystic' mixtures and sometimes rather unsuccessful results." Cummings (1997) talks of glass moulds in the following terms; "These materials and the mixes described have been developed over 30 years, which is the life of the modern kiln-formed movement. They are the result of much trial and error, and although they work well and are now in world wide use, they must be subject to continual improvement and substitution". Thus, there is a clear need for effective development and communication of formulation, especially in these days, where there is much less continuity of tradition in fine art or craft.

The development of engineering design, and the associated dialogue between engineers, has brought about a divergence between engineering practice and craft to the extent that the methods of engineering are totally inaccessible to practitioners. Coupled with this, has been a divergence in production and fabrication methods, where the drive in engineering has been to control quality (expressed in terms of functional soundness), reproducibility, reliability and manufacturing efficiency, which often results in reduced manual human contact with the production process. The drives are almost diametrically opposite in craft where "defects" are valued as a measure of uniqueness and the maintenance of physical contact between the craftsperson and the object being crafted is of the utmost importance. On the other hand, it must be accepted that the media with which artists work change with time and there is a need for practitioners to be able to come to some accommodation with the technology.

Summarising, then, the thesis is built on the following two contentions:

- that fine art practitioners do not communicate effectively the methods which they use, relying mostly on direct contact between emerging practitioners and experienced craftspeople.

- that engineers, by contrast, have developed a whole language of specification and communication of process, but this is completely inaccessible to fine art practitioners.

This work, therefore, aims to produce a methodology, applied to formulation, which can be communicated from practitioner to practitioner, and which is based on the rigour of engineering practice but employs a vocabulary which fine art practitioners can understand.

**Fig. 1 Vase drawing from 5$^{th}$ Century BC (Traced from John and Ely, (1979))**

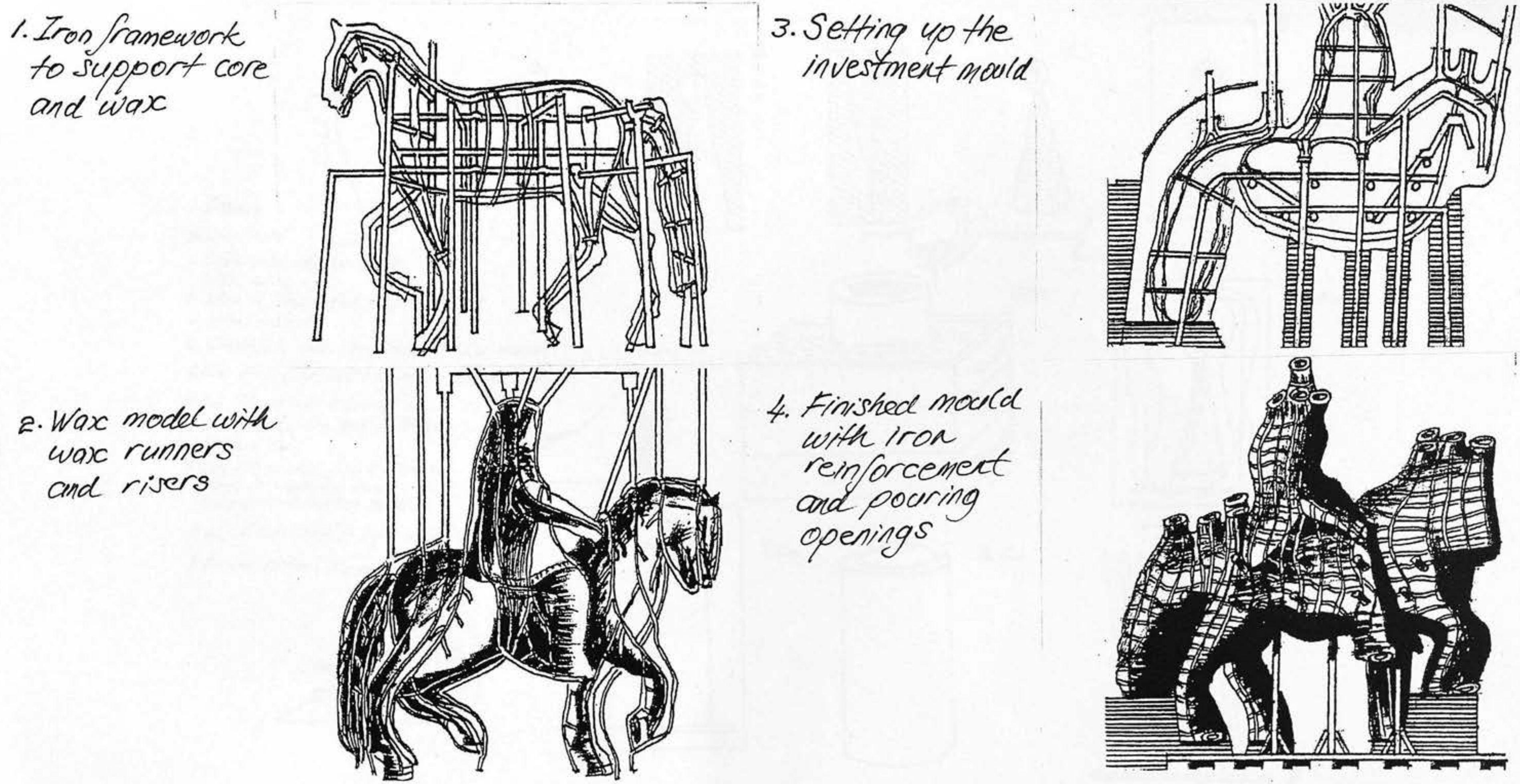



**Fig. 2 Drawings based on 18th century illustrations of a report on the casting of a bronze of Louis XIV (adapted from John and Ely, (1979))**

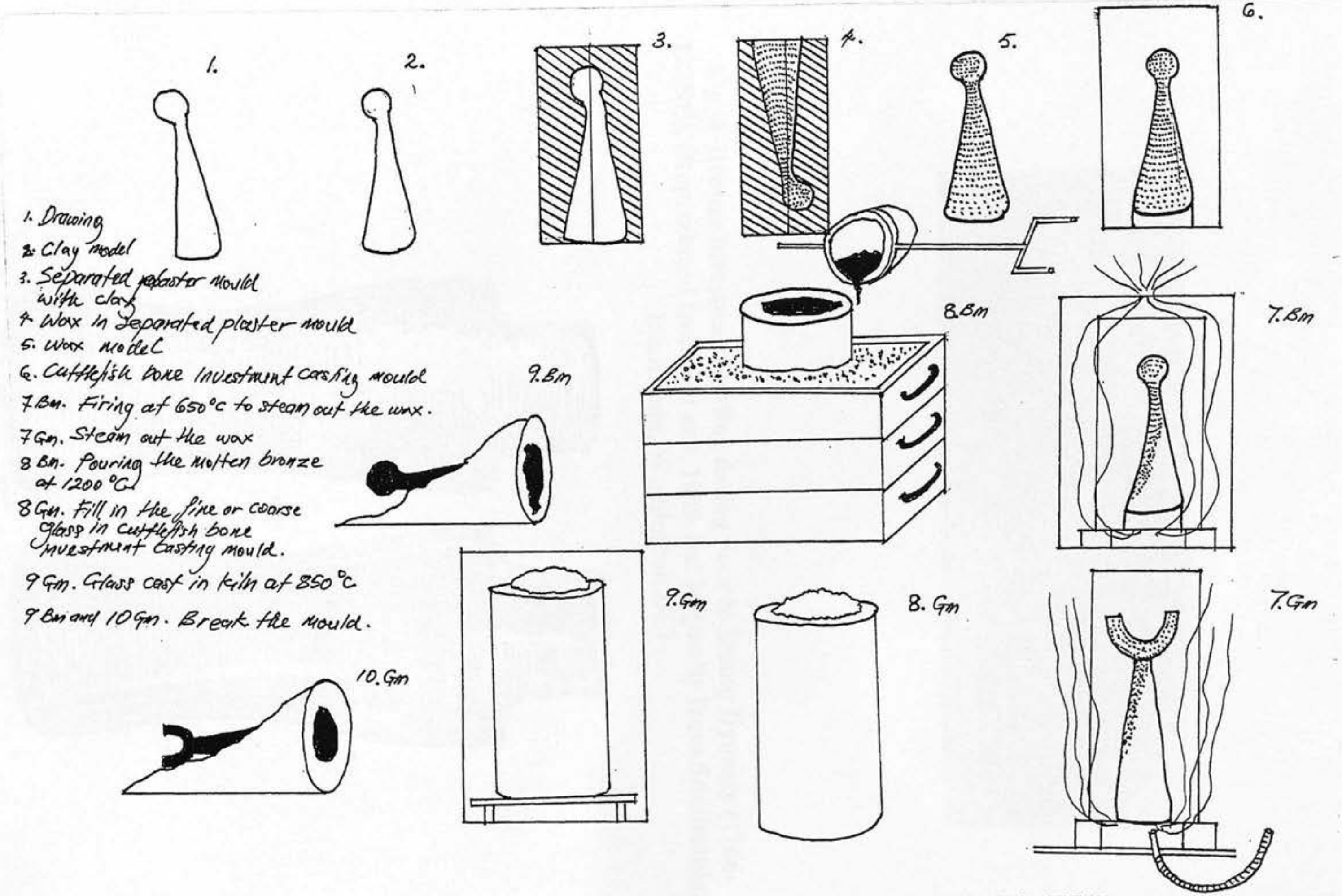



Fig. 3 Process variants used in this work for bronze and glass casting

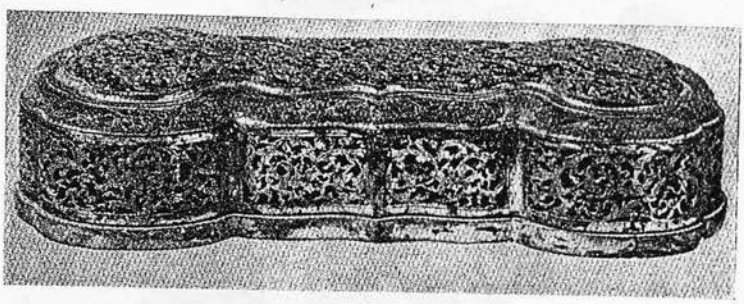


**Fig. 4 Bronze investment casting dating back to Shang Dynasty (1766-122BC). (Reproduced from Bidwell, 1969, but originally from Smithsonian Institution, Washington DC)**

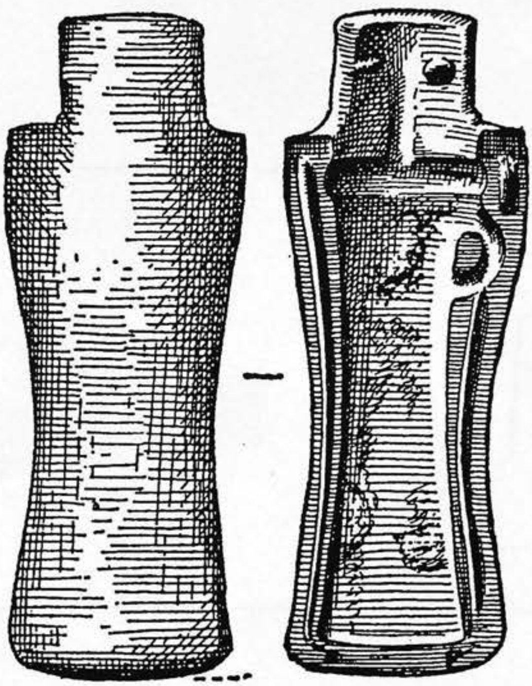


**Fig. 5 Bronze Age mould made from bronze. (Reproduced from Tylecote, 1962, but originally courtesy of British Museum.)**


**Fig. 6 Microscope drawing of foundry moulding sand. (From Bagshaw, 1891).**

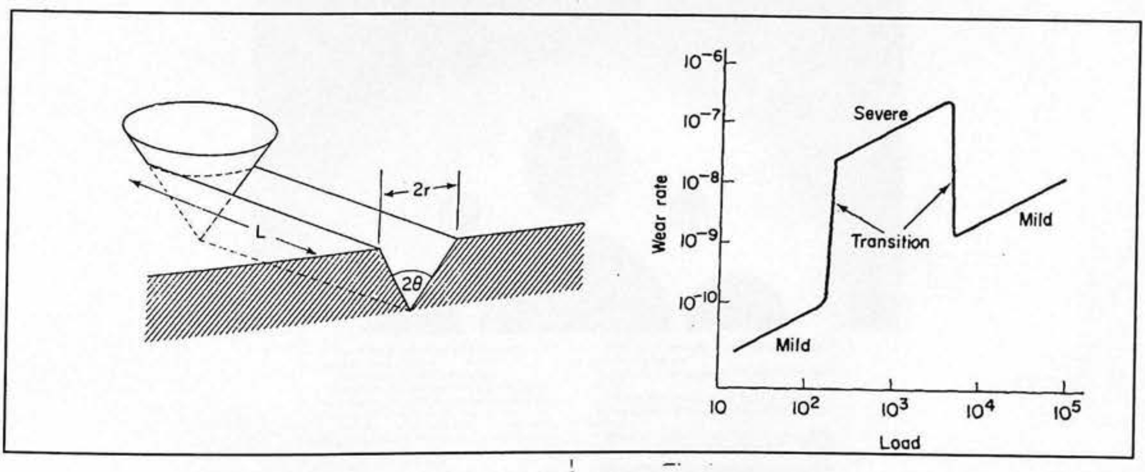
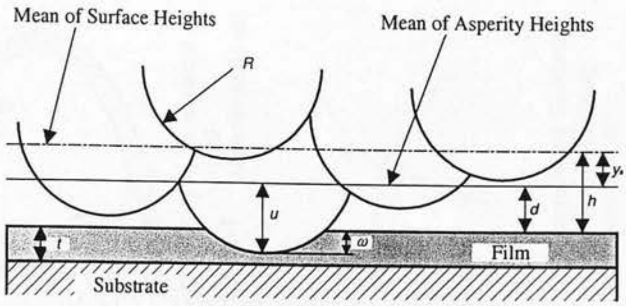



**Fig. 7 Physical modelling and empirical measurement in the treatment of wear problems. (Compiled from Halling, 1976.)**




$$P^*(h^*) = \frac{4}{3}\beta(\frac{\sigma}{R})^{1/2}\int_{h^*-y_s^*}^{h^*-y_s^*+\omega_c^*}\omega_s^{*3/2}\phi^*(u^*)du^* + \frac{\pi H_e\beta}{E}\int_{h^*-y_s^*}^{h^*-y_s^*+\omega_c^*}(a_c^{*2} - a_s^{*2})\phi^*(u^*)du^*$$

$$+\frac{\pi\beta Y}{E}\int_{h^*-y_s^*+\omega_c^*}^{\infty}(2\omega_s^* - \omega_c^*)[3 + (\frac{2K}{3} - 3)\frac{\omega_c^*}{\omega_s^*}]\phi^*(u^*)du^*$$

$$+\frac{\pi H_e\beta}{E}\int_{h^*-y_s^*+\omega_c^*}^{\infty}(a_c^{*2} - a_s^{*2})\phi^*(u^*)du^*$$

**Fig. 8 Tribological model for surface contact. (Compiled from Zhqiang Liu *et al*, 2000)**

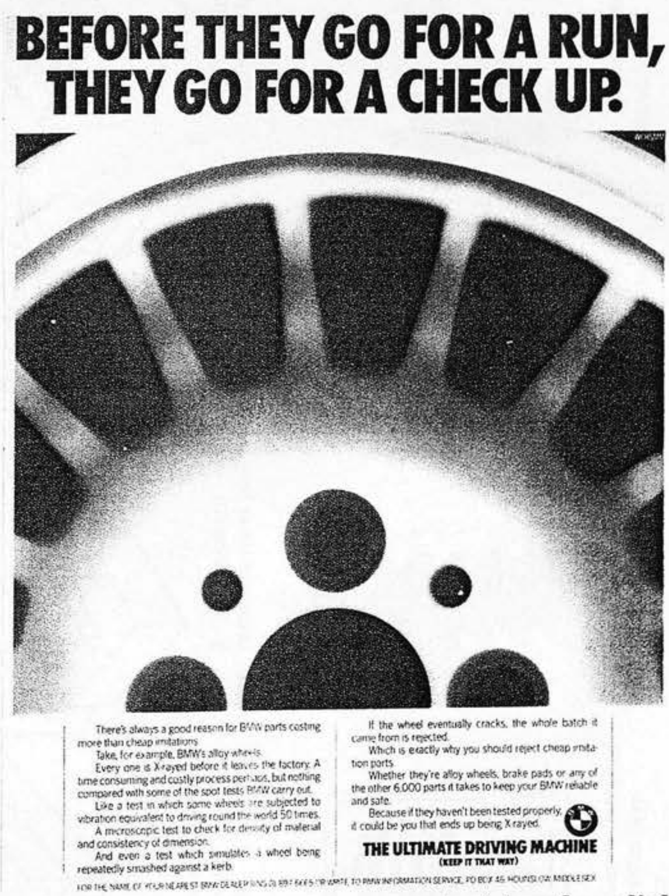



**Fig. 9 Advertisement for car company emphasising the reliability requirements for cast alloy wheels**

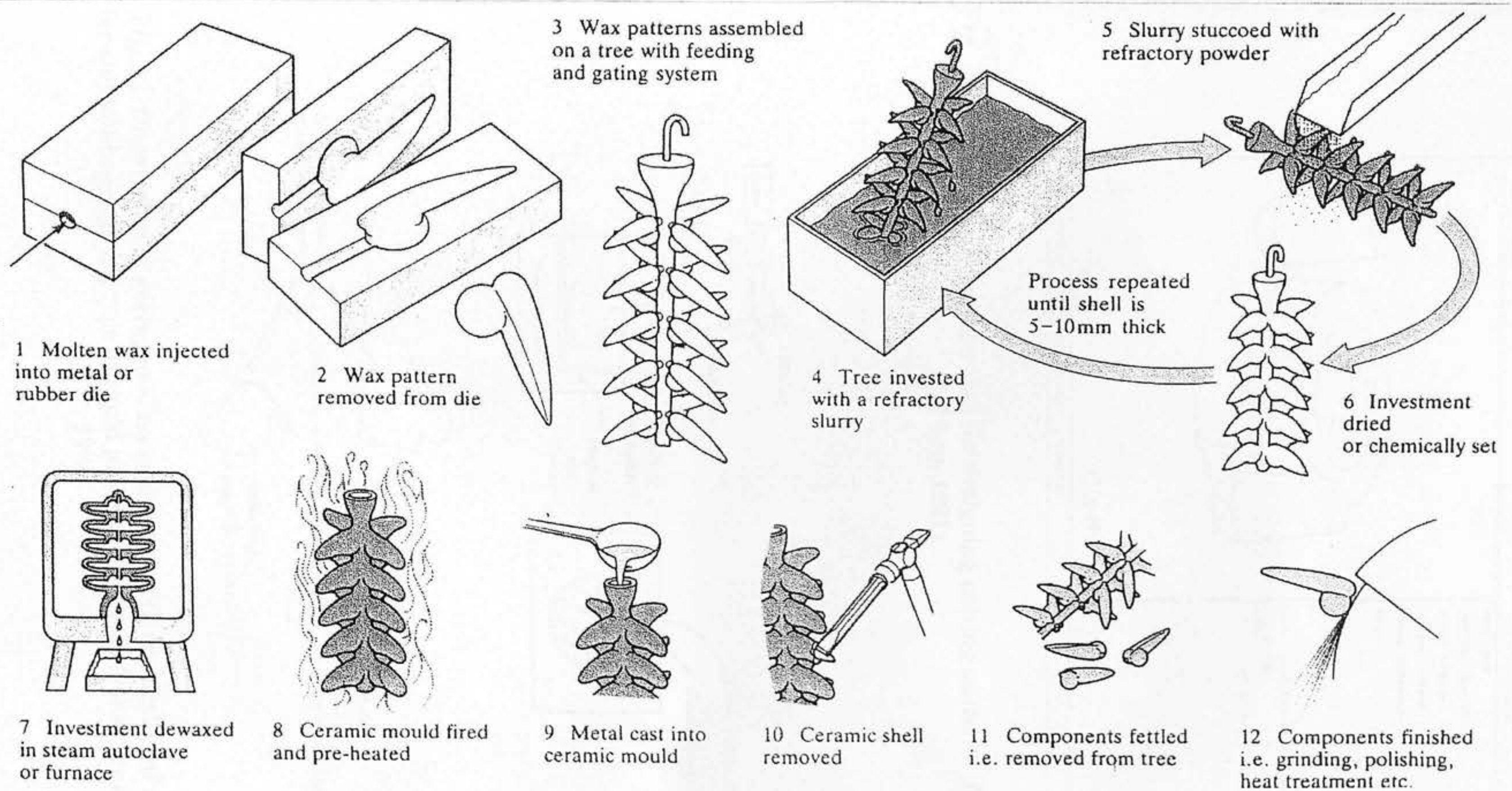



Fig.10 Schematic of modern industrial ceramic shell investment casting process for production of hip prostheses (from Edwards and Endean, 1990)

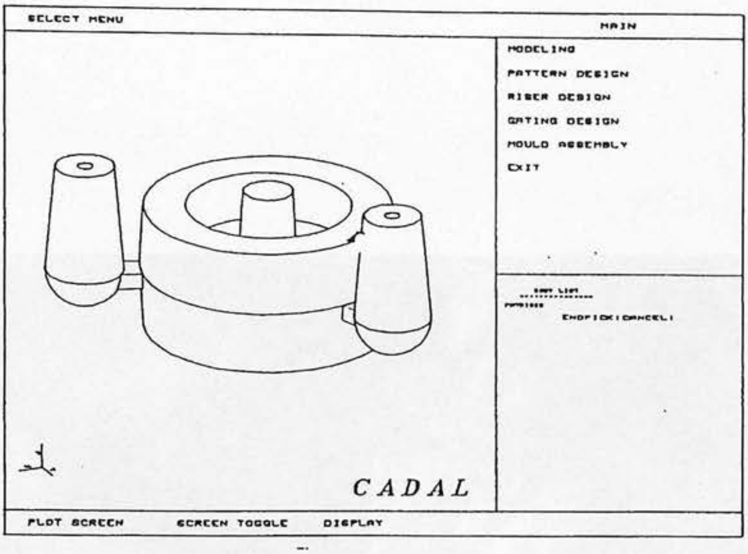



**Fig. 11 Screen from computer tool for designing casting patterns (from Park and Lee, 1991)**

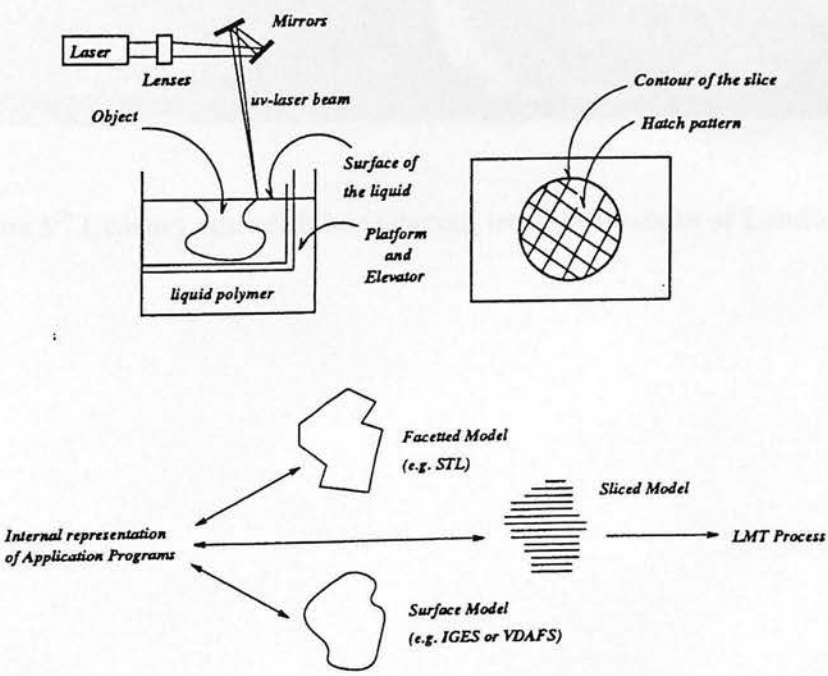



**Fig. 12 Illustration of slicing process associated with the design of an object for stereolithography, a type of rapid prototyping (from Dolenc and Mäkelä, 1994)**

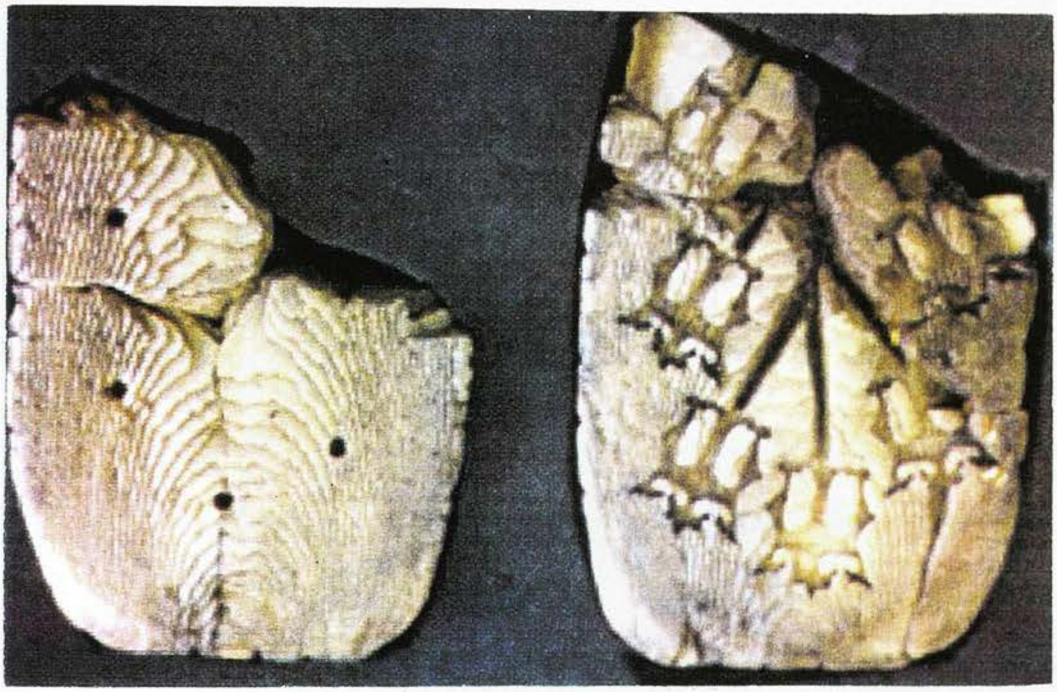


**Plate 1 Late 5th Century cuttlefish bone carved mould (Museum of London)**

# Chapter 3. CULTURAL CONTEXT OF THE RESEARCH.

## 3.1 Introduction

This chapter outlines who the research is directed towards and how this influences the development of the methodology of experimentation. Much of the information referred to here is unpublished and a process of semi-structured interviews was carried out in Malaysia and also in Scotland, as well as reference to the Internet in order to elicit as much information as possible on such a diffuse topic.

The research is directed in the first place to the cultural context in Malaysia (explored in the process of acquiring the material) and in the second place to other practitioners of Fine Art and Craft elsewhere, as discussed in Chapter 2.

The cultural context of Malaysia is significant because, apart from being the home of the author (Fig.13), cuttlefish bone is a waste material produced by the not insignificant local fishing industry. Thus, the research has possible impact in small industries, the teaching of craft, and for extended use in craft as a substitute for expensive grogs.

This chapter demonstrates that:

- cuttlefish bone as a whole entity is currently used in the casting of jewellery, but not cuttlefish bone powder as part of the investment casting process for bronze and glass
- cuttlefish bone powder is obtainable by careful selection of sources of the bone itself and subcontracting and supervision of the crushing process

• there are no known formulations for the use of the cuttlefish bone powder as an ingredient in investment casting

Therefore there is a need to develop a formulation for investment casting which is reliable, and in which cuttlefish bone powder is a significant ingredient. This will be explored in two stages and described in detail in Chapters 4 and 5:

i. The development of a slurry technique that fulfils stated criteria (Chapter 4)

ii. The testing of a selected number of moulds for heat resistance within the investment casting process for both bronze and glass (Chapter 5)

Different uses for cuttlefish bone will be described drawing on a variety of sources. Some of these sources describe the use of cuttlefish bone in its entirety within jewellery, both in Malaysia and in Scotland. The process of sourcing and acquiring cuttlefish bone powder for the purposes of this research is also detailed. This experience informed the researcher as to the availability of cuttlefish bone in its powdered form, thus impacting on the sustainability of its use within small industries once the research has been successfully completed. The process of acquiring the material also suggested that no-one was using cuttlefish bone in its powdered form as an ingredient for investment casting. It is acknowledged that this is not conclusive, but only informed through the process of acquiring the material for the purposes of experimentation outlined in Chapters 4 and 5.

### 3.2 Uses of cuttlefish bone.

Cuttlefish bone as a whole entity is currently used in the casting of jewellery, as will be demonstrated with reference to jewellers both within Malaysia and within

Scotland. The evidence has been acquired in part through interviews and in part from other sources such as the Internet. A list of the names of those interviewed is given at the end of this chapter.

***Uses other than casting***

Cuttlefish bone, referred to by Crystal (1997) as "the internal calcareous shell of a cuttlefish", is a waste material that can be easily obtained from the coastal areas in Malaysia. Despite its name, it is not the bone of a fish, but is the light, porous mass, mainly of calcium carbonate, which forms the internal skeleton of the cuttlefish, which is related to the squid (Plate 2).

In the past, only a small group of people, namely in the Malay and Chinese societies, knew of its uses. For example, the Malays used cuttlefish bone as a material for pet doves (Merbuk and Terkukur) to peck on so as to sharpen their beaks with the intention of strengthening them and also to improve the birds' singing. This, of course, is its main known use in modern times both to keep birds' beaks in condition (www.petnet.com.au) and for the minerals it contains (www.petbirdxpress.com). The Chinese people have used cuttlefish bone in the past as a facial powder, as it was believed to make the face smooth.

Mead and Beckett, (1984) have said of cuttlefish *Sepia Latimanus*: "Few people realise that the cuttlefish bone we give to cage birds to keep their beaks in trim is the internal bone of a squid, the cuttlefish", and Hayward et al (1996) note of another common species *Sepia Officinalis Linnaeus*: "Found on all coasts; very good for budgerigars".

Other uses of cuttlefish bone, according to Ayres (1985), include erasers used by sculptors to remove pencil lines from stone and marble, and the Chambers Dictionary (Davidson et al., 1997) suggests that it is used for making tooth powder and for polishing metals.

A recent excavation of a Chinese work-camp of the late 19th Century (Yema-po) revealed cuttlefish (as evidenced by bone debris) to have been an important part of the workers' diet, and it was listed in customs documents as a major import to San Francisco from China in the 1870s (www.isis.csuhayward.edu). The fact that this debris was found indicates that the supply outstrips the demand in societies where cuttlefish are eaten.

***Use for casting***

Traditionally, cuttlefish bone has been used for casting jewellery, for example by goldsmiths for making rings (Pearsall, 1999). This use of cuttlefish bone is well known in Malaysia, as evidenced by interviews conducted in Malaysia with practitioner jewellers. For example Mr. Mohd Zueliq Mohammed and Mr. Wan Md. Nassaruddin Hj. Wan Ahmad both said that they had been in the practice of using cuttlefish bone for making ring moulds for at least 10 years. Ian Davidson said that the cuttlefish bone was a very suitable material for making simple moulds where only one casting is required, and that this material can be obtained from jewellers' suppliers and sometimes from pet shops.

McGrath (1995) has described two very quick and simple methods for casting using cuttlefish bone. The first is simply to carve the required shape and depth of pattern into one side of the halved cuttlefish bone before pouring. The alternative method consists of making a pattern in perspex or metal, then pushing this into a half shell of bone until it is buried to about half its depth. The other half shell is made similarly. Choate (1975) has mentioned that expensive equipment is not required. Although the cuttlefish bone can be used for only one casting (casting sand, for example, can be reclaimed for multiple use), the procedure is much easier and quicker than for sand casting. The larger cuttlefish bones required for the casting process are sold by casting supply houses for the use of the jewelry craftsman, the largest sizes being 12 inches and 14 inches.

Gaukler (www.medievalwares.com ) all of whose bronze and brass is poured into cuttlefish bone moulds, claims to have documentary evidence for this type of mould being used in the late 14th Century, and indicates that the Museum of London has a late 15th Century cuttlefish mould in its collection (Plate 1).

### 3.3 The sourcing of cuttlefish bone in Malaysia.

A number of local suppliers of cuttlefish are listed with the Fisheries Development Authority of Malaysia (LIKM). There are three companies, respectively in Penang, Selangor and Perak. All companies are located on the West Coast of Malaysia, facing the Strait of Melaka. The export products from the companies are wet, fresh and frozen cuttlefish.

***Selection of suppliers***

Because LKIM list a range of cuttlefish suppliers, there is no problem in finding a supply of cuttlefish bone, which must necessarily be removed from the animal anyway (Plate 3) . A good supplier is judged on the following criteria:

1. The size of the dry cuttlefish bone (for traditional casting)

2. The quantity of dry cuttlefish bone available

3. The cost of the dry cuttlefish bone supply per kilo

4. The distance from the supplier of the dry cuttlefish bone to the University of Technology Mara (UiTMara ), where grinding and crushing was carried out

The (LKIM) list is shown in Table 1, and two suppliers were selected against the above criteria, Sea Master Trading Co. Sdn. Bhd., located in Penang in North Malaysia, and San Hup Huat Seafood Sdn. Bhd., located in Perak in Central Malaysia.

According to Mr. Chew of San Hup Huat Seafood, the company catches more than 500 kilos of cuttlefish per day and Australia is the main importer of their dry cuttlefish bone. Mr Ng Bak Hwa of Sea Master Trading said that the company had been operating for more than 20 years and catch sizes varied from about 300 to 500 kilos per day. North America was their major importer of the cuttlefish bone, which was selling at RM2.50 per kilo.

### 3.4 The production of cuttlefish bone powder

A total of 500 kilos of bone was purchased from one of the suppliers at a total cost of RM 500. Once delivered, the cuttlefish bone needs to be ground into powder. This was done manually using permanent helpers, Nazri Ahmad, Nazrul Abdullah and Izmahina Mat Ariffin, who were each paid at RM 12.00 per 8-10 hour day.

| Locality | Company Name | Company address | Company activity | Product | Export |
|---|---|---|---|---|---|
| Penang | Sea Master Trading Co. Sdn. Bhd | 2446 MK 1 Solok Perusahaan Satu Prai 13600 Butterworth | Exporter | Wet, Fresh & Frozen | Singapore,Thailand, Taiwan, Japan & S. Korea |
| | Versal Air Services | 1. Penang Flying Club Building 11900 Bayang Lepas | Exporter | Wet, Fresh & Frozen | Singapore, Japan, Hong Kong & S.Korea |
| | Tropical Consolidated Corpn. Sdn. Bhd | 14, Danby Street, 14000 Bukit Mertajam | Exporter | Wet, Fresh & Frozen | Singapore,Australia, Canada, USA, Taiwan, Switzerland & Brunei |
| Selangor | Ng Emas Marketing Sdn, Bhd. | 4, Jalan SS20/10, Damansara, 47000 Petaling Jaya | Exporter | Wet, Fresh & Frozen | Singapore, Taiwan & Hong Kong |
| | Water Fresh Food Sdn. Bhd. | Rumah Sembelih Shah Alam | Exporter | Wet, Fresh & Frozen | Japan, India, Bahrain & France |
| | Lee Coldstorage, Sdn. Bhd. | Lot 729, Batu 2 ½ Jln Sungai Rasa,Padang Jawa | Exporter | Wet, Fresh & Frozen | India, Bangladesh & Kuwait |
| Kuala Lumpur | A Aquarium Enterprise | 560 Jln E3/5 Taman Ehsan 52100 Kepong | Exporter | Wet, Fresh & Frozen | Singapore |
| Perak | San Hup Huat Seafood Sdn. Bhd. | Hutan Melintang | Exporter | Wet, Fresh & Frozen | Australia |

**Table 1 List of cuttlefish bone suppliers in Malaysia**
**Source: LKIM (Fisheries Development Authority of Malaysia)**

***The grinding process***

The grinding process took 19 days to produce 400 kilos of powder, 293 kilos of fine cuttlefish bone powder and 107 kilos of coarse cuttlefish bone powder, giving a total labour cost of RM. 684.00.

The grinding process was manual and used only simple tools:

i. Wooden mortar and wooden pestle (Plate 5)

ii. Stone mortar and stone pestle (Plate 6)

iii. Sieve (Plate 7)

The hard shell which is located at both sides of the bone has to be pulled off and thrown away (Plate 4), as it cannot be mixed together with the soft (fresh) cuttlefish bone and this resulted in a total weight of the unused hard shell of 100 kilos. Then, the soft portion was broken into small pieces, using a hammer, and then ground into powder using the wood and stone mortars and pestles (Plates 5 and 6). The sieve was used to separate the powder into two grades, fine and coarse, as shown in Plate 8.

.

***Packaging and shipping***

The 400 kilos of powder was kept in a dry place and then packed into 21 postal boxes, each box weighing approximately 20 kilos. The boxes were then shipped to Edinburgh College of Art for further studio experiments. The total cost for shipping the cuttlefish bone was RM 2519.90 (£ 503.98).

### 3.5 Uses of cuttlefish bone powder

Although it is a relatively small sample, a total of six fine art founders, jewellers and practitioners were interviewed in order to establish if any experience existed amongst them for the use of cuttlefish bone powder for investment casting moulds. Of the six, four had heard of the use of cuttlefish bone for jewellery casting, and three of these had connections with jewellery (one as Head of a Jewellery Department and two as practitioners). The third was Malaysian, and was a technical director in investment casting. The fact that he knew of no uses of cuttlefish bone powder for investment casting moulds is therefore significant. Another Malaysian investment caster, and one who used traditional moulding materials, including rice husk and beach sand, had not heard of the use of cuttlefish bone for casting at all. A (Scottish) fine art bronze founder had equally not heard of uses of cuttlefish bone.

Although this hardly constitutes proof that the approach is novel, the author felt that the lack of knowledge of potential use of cuttlefish bone powder as an extender for investment casting moulds warranted the investigation of such use as a research topic in its own right.

### 3.6 Summary and direction of experimentation

It has been seen that cuttlefish bone is currently used in the casting of jewellery, and its properties are evidently known world-wide, as well as in Malyasia. The method involves carving directly into the bone, and obviously the scope of its use is confined to relatively small objects. There is therefore a case for developing formulations including cuttlefish bone powder as part of the investment casting process for bronze and glass sculpture.

Cuttlefish bone is readily available in Malaysia. Furthermore, it is a waste material since there is over-supply of the traditional market for cage birds, leading to a depression in price. These factors led the author to look for new applications for the powered bone which exploit its obvious properties for casting moulds.

However, there appear to be no known formulations for the use of cuttlefish bone powder as an ingredient of investment casting. Therefore there is a need to develop a formulation which is reliable, and in which cuttlefish bone powder is a significant ingredient. This will be explored in two stages:

- Phase I Experiments : The development of a slurry technique for bronze and glass moulds (Chapter 4)
- Phase II Experiments: The testing of heat resistance of successful moulds from Phase I for bronze (Stage 1) and glass casting (Stage 2) (Chapter 5)

## List of interviewees

EDINBURGH

Mr Ian Davidson, former Head of Department of Jewellery at Edinburgh College of Art.
Interviewed 21st January 1998

Mr Kerry Hammond, bronze fine art founder.
Interviewed 16th February 1998

MALAYSIA

Mr Ng Bak Hwa, exporter and supplier of marine products.
Interviewed 13th April 1998

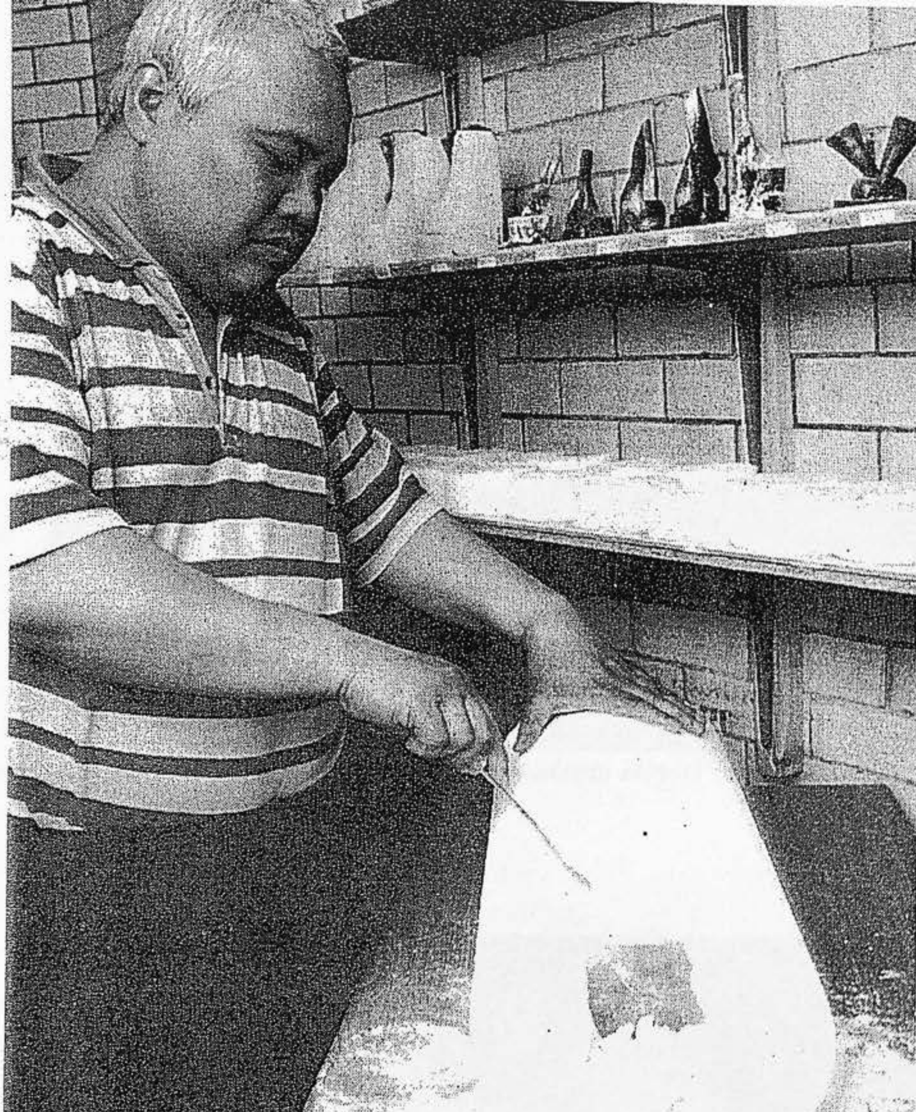
Mr Chew, supplier of cuttlefish bone
Interviewed 14th April 1998

Mr Mohamad Sabri Abdullah, technical executive (investment casting technology)
Interviewed 3rd May 1998

Mr Omar bin Mohammed, traditional investment casting mould maker.
Interviewed 4th May 1998

Mr Mohd Zueliq Mohammed, jeweller
Interviewed 3rd May 1998

Mr Wan Md. Nasaruddin Haji Wan Ahmad, jeweller
Interviewed 28th May 1998



14 The Sun Saturday August 5, 2000

Ahmad Rashdi works on a casting mould made of discarded cuttlefish bones at the Edinburgh College of Art. – BERNAMAPIX

# Cuttlefish bones for casting moulds

**LONDON,** Fri: A Malaysian student of sculpture has earned a place at the prestigious Edinburgh International Festival Fringe early this month, thanks to cuttlefish bones.

This Edinburgh College of Art student, who is in a class of his own doing a PhD in Sculpture, has discovered a use for discarded cuttlefish bones to make casting moulds.

University of Technology Mara lecturer Ahmad Rashdi Yan Ibrahim, 45, was searching for an alternative material to be added to bronze and glass when he thought of cuttlefish bones.

"History has proved that cuttlefish bones have long been used by Malay goldsmiths as direct mould castings to make rings," said Kuala Kangsar-born Ahmad Rashdi.

He proceeded to improve on the idea by mixing powdered cuttlefish bones to existing refractory bronze and glass materials.

Ahmad Rashdi gathered the bones on one of his field trips home and brought them back in powder form to Edinburgh.

Sirim, the Malaysian standards certification agency, has certified that cuttlefish bones contain 38% calcium, which contributes to the heat resisting characteristics of the material, making it ideal for casting moulds.

Ahmad Rashdi, who is in his final year, said he is the first and only student to do a PhD in Sculpture and hopes that his discovery can also be used in other related discipline. – Bernama

HOME NEWS

**Fig.13 Press cutting from *The Sun* of Malaysia highlighting the author's work (August 2000)**


**Plate 2 Cuttlefish** ***(Sepia Esculenta Hoyle)***


**Plate 3 Method of removal of cuttlefish bone**

**Plate 4 Dry cuttlefish bone**

**Plate 5 Wooden mortar and pestle used for grinding**


**Plate 6 Stone mortar and pestle used for grinding**

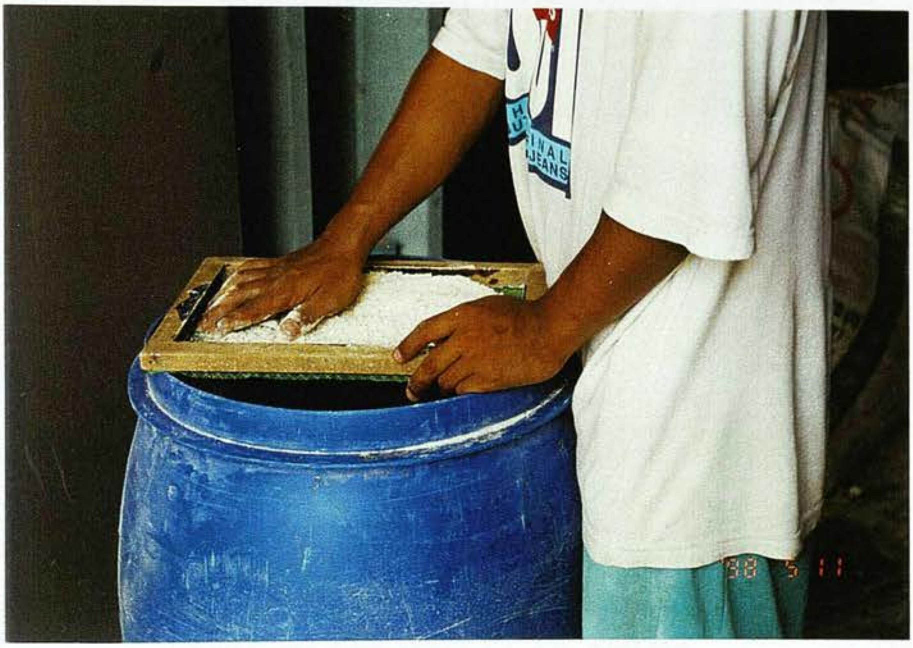


**Plate 7 The sieve**

Plate 8  Samples of fine and coarse cuttlefish bone

# Chapter 4. EXPERIMENT 1 – HANDLING AND SETTING OF MOULD MATERIAL.

## 4.1 Introduction

When faced with developing a new formulation for sculpture moulds, it is necessary to ensure that the wet mix has adequate handling characteristics and that it will harden acceptably. This chapter relates the approach used for formulations involving cuttlefish bone. The approach used is essentially iterative trial-and-error in that a series of mixes was chosen and, on the basis of the behaviour of a few mixes, a new set was devised. This process involved subjective judgements of handling criteria and it was this subjectivity which suggested that an enhanced understanding of the mixture might be useful.

Most modern sculpture moulds for investment casting are made from a mixture of plaster of Paris, brick powder and pulverised ceramic piping (grog) or other refractory. Based on the required handling and setting characteristics, a set of three criteria were used to determine acceptability of the mixtures (Schuler, 1971):

1. After hand stirring for 5 to 10 minutes, the mixture should take on a creamy consistency. Such a consistency allows the slurry to take fine detail without being so thin as to run off the positive. It is also known that very thick mixtures tend to make brittle and / or excessively hard moulds.

2. The mixture must set hard within 10 to 30 minutes of pouring. Early setting can be indicative of poor quality plaster, but is also undesirable from the handling point of

view. Mixtures that do not set hard within 30 minutes are unlikely to set at all unless a significant period is allowed for water evaporation.

3. When the mould has set there should be no water remaining on the surface. Remaining water is an indication of insufficient cement to use up the water and will give rise to a weak mould.

## 4.2 Materials.

A number of different possible dry ingredients can be used for bronze and glass investment casting moulds. These traditional ingredients are described briefly below.

i. Fine casting plaster (plaster of Paris)

Fine casting plaster is one of the most extensively used materials in the sculptor's repertoire. It is used in mould making for its cementitious properties. The material derives its name from the earth of Paris and its surrounding regions, which contain an abundance of the parent mineral gypsum, from which plaster of Paris is manufactured. Gypsum is calcined after extraction to produce a hemihydrate of calcium sulphate, which, when exposed to water, slowly absorbs it and then crystallizes. This process produces hardening although the final structure is not as strong as civil engineering cements.

ii. Fine grog (sieve mesh 85 and under)

Grog is also produced by calcining a natural mineral, in this case clay (Rich 1974). The term "clay" describes a number of minerals, but these are mostly hydrous view. Mixtures that do not set hard within 30 minutes are unlikely to set at all unless a significant period is allowed for water evaporation.

3. When the mould has set there should be no water remaining on the surface. Remaining water is an indication of insufficient cement to use up the water and will give rise to a weak mould.

## 4.2 Materials.

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i. Fine casting plaster (plaster of Paris)

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ii. Fine grog (sieve mesh 85 and under)

Grog is also produced by calcining a natural mineral, in this case clay (Rich 1974). The term "clay" describes a number of minerals, but these are mostly hydrous aluminum silicates with very fine particle size and which become plastic when a small amount of water is added. Grog is occasionally added as a refractory material to bronze investment casting moulds to reduce shrinkage and warping.

iii. Coarse grog (sieve mesh 5 and under)

This is the same material as fine grog, but different in size.

iv. China clay.

China clay is a high grade kaolinite and is a white clay that can be fired. It is not employed by itself as a moulding clay because it is not sufficiently plastic in its pure form. The fired substance is very porous and exhibits low shrinkage, which makes it capable of drying and firing with minimum danger of warping and cracking.

v. Molochite.

Molochite is calcined china clay, often used as a relatively iron-free grog to reinforce the refractory clays for making mould pots. When china clay is calcined, the resulting molochite contains mullite and amorphous silica glass which gives the material a low thermal expansion and high resistance to thermal shock. These qualities, coupled with the low-iron content, make the material ideal for use as a grog in pot making (Bray, 1995, p. 160).

vi. Fine building sand.

This is fine sand as is normally used in building construction, and is sometimes used in investment casting moulds as a refractory bulking agent.

vii. Vermiculite.

Vermiculite is formed by altering a natural mineral biotite, which is a member of the mica group (Hurlbut and Klein,1977). When heated, vermiculite is formed by the cleavage of plates, to make a very light refractory material, which is often used for thermal insulation. It is sometimes mixed with alumina cement and used as an exterior layer on kilns and furnaces, and is also used to reduce the cooling rate of annealed artefacts. (Bray, 1995, p. 219)

viii. Flint.

Flint is a granular form of natural quartz, usually found as nodules in chalk (Hurlbut and Klein, 1977). When powdered, it is used to replace sand as a batch material but it is much more expensive and therefore it is only used rarely and for specific purposes such as investment casting of glass. In its natural state, flint it is extremely hard and is normally calcined which has the effect of softening it sufficiently to grind easily to produce a white powder (Bray, 1995, p. 110).

ix. Glass old mould.

This is a refractory material made from fired glass investment casting moulds, which have been ground down. As such, its ingredients are relatively uncontrolled.

x. Silver sand.

Silver sand can be used as a strengthening agent and as a major ingredient in some lower temperature moulds (Cummings, 1997, p 150).

xi. Glass fibre.

Glass fibre is produced by drawing and is mainly used as a reinforcement for plastic materials. This material is used for glass investment casting moulds in Edinburgh College of Art.

In addition to the above, cuttlefish bone powder was used as a dry ingredient in two size ranges, coarse and fine. This material, and its processing is described in detail in Chapter 3.

A typical bronze investment casting mould will contain about 30% casting plaster, 10% clay and 20% each of molochite, fine grog and coarse grog in the dry ingredients, with a little over half the same volume of water. The approach has therefore been to try to substitute as much of the non-cementitious material as possible with fine or coarse cuttlefish bone powder.

For glass moulds, the numbers of different aggregate materials used is generally higher, although the proportion of plaster in the dry ingredients tends to be higher, typically 50%. The reason for this is that glass moulds are heated in a kiln and therefore need to be stronger since they cannot be reinforced by a sand pit as is the case when pouring bronze.

### 4.3 Experimental procedure.

The handling and setting experiments were carried out by pre-mixing the dry ingredients in 0.5 kg batches. The materials were weighed, but, for the purposes of later visualisation, the volume occupied by a unit weight of each of the dry ingredients was also determined. These volumes per unit weight are shown in Table 2. Henceforth, only volumetric percentages will be used and it should be appreciated that these are different to weight percentages.

| **Material** | **Volume ($cm^3$) / kg.** |
|---|---|
| Water | 1000 |
| Fine casting plaster | 1600 |
| Fine cuttlefish bone powder | 1400 |
| Coarse cuttlefish bone | 1600 |
| Fine grog | 800 |
| Coarse grog | 800 |
| China clay | 2800 |
| Molochite | 1000 |
| Fine building sand | 800 |
| Vermiculite | 10000 |
| Flint | 1400 |
| Glass old mould | 2000 |
| Silver sand | 800 |
| Glass fibre | 4000 |

**Table 2 Volume of 1 kg of each of the dry materials.**

Water was then added (again calculated on a volumetric basis) and the mixture stirred by hand for 5 to 10 minutes. This procedure is relatively standard: "Sift premixed dry ingredients into the water and stir with fingers constantly to keep the heavy compounds in solution, taking care not to entrap air. Vibrating the mixing container will assist the removal of air bubbles. Investment is ready for pouring when the surface resists finger marks. Thicker consistency is necessary when it is to be dipped or brushed, as in a facing coat", (Widman, 1971 p.154).

Once the mixture had turned creamy (or not, as the case may be) it was poured into a roller zinc (a cylinder of zinc used to hold the mixture) to make the investment casting moulds. During the experiments, observations were made of the development of consistency, the time taken for the mould to set and whether or not water remained on the surface. Plate 9 shows a typical form used for assessment of the moulding materials. Rough notes, taken at the time of experimentation are compiled in Appendix 1 (for bronze moulds) and Appendix 2 (for glass moulds).

As there are 14 possible different ingredients, a method was required to investigate the replacement of refractory material with cuttlefish bone without carrying out an excessive number of trials. Firstly, the experiments were divided into those directed towards bronze moulds and those directed towards glass moulds.

Because the formulations are quite difficult to visualise, these have been represented in a colour–coded graphical form (Fig. 14–17) which can be folded out from the thesis.

## 4.4 Experiment I, Part I: The slurry technique for bronze casting moulds

Figures 14 and 15 summarize the bronze mould trials in terms of the dry ingredients and slurries respectively. The trials can be sub-divided into four categories:

1. Dry mixture containing cuttlefish bone and casting plaster only.
2. Dry mixture with some added grog.
3. Dry mixture with some added china clay.
4. Other mixtures.

The general approach was, firstly, to find any formulations containing only fine cuttlefish bone powder and fine casting plaster, which would handle and set acceptably (mixtures 1-8). Then the conventional refractories and china clay were added to give a range of formulations to take forward to the heat resistance trials (mixtures 9-32).

### *4.4.1 Cuttlefish bone powder mixtures ( mixtures 1-8 )*

In this series of trials, three different ratios of fine cuttlefish bone powder to fine casting plaster were used (Fig. 14). The amount of added water (Fig. 15) was also minimised. Of these mixtures, only mould 8 met the evaluation criteria, the other mixtures tending to be soft when set, with water remaining on the top of the mould.

| **Mixture** | **Total weight of cuttlefish bone powder (kg)** | **Criterion** | | |
|---|---|---|---|---|
| | | **1: Consistency** | **2: Setting time** | **3: Excess water** |
| 1 | 0.25 | ✘ | ✘ | ✘ |
| 2 | 0.25 | ✘ | ✘ | ✘ |
| 3 | 0.15 | ✘ | ✘ | ✘ |
| 4 | 0.25 | ✘ | ✘ | ✘ |
| 5 | 0.25 | ✘ | ✘ | ✘ |
| 6 | 0.15 | ✔ | ✘ | ✘ |
| 7 | 0.25 | ✘ | ✘ | ✘ |
| 8 | 0.125 | ✔ | ✔ | ✔ |

**Table 3 Summary of slurry behaviour against total weight of cuttlefish bone powder (bronze moulds 1 – 8)**

### *4.4.2 Dry mixture with added grog ( mixtures 9-13 )*

In this series of trials, a common refractory (grog) was added to the dry ingredients. In moulds 9 and 10 fine grog was substituted for some of the plaster of the successful mould 8, but using the same volume (or less) of water the mixture failed to set. Because these mixtures were too stiff, the proportion of plaster was reduced further and exceptionally the total weight of dry ingredients was reduced to 3/8 kg (mould 11) the mixture still did not set with 400 ml of water (Appendix 1). Next, the amount of plaster was increased and two moulds (12 and 13) were found to set with either fine or coarse grog. After this series of experiments neither the weight of dry ingredients (0.5 kg) or the volume of water (400ml) was varied again.

| **Mixture** | **Total weight of cuttlefish bone powder (kg)** | **Criterion** | | |
|---|---|---|---|---|
| | | **1: Consistency** | **2: Setting time** | **3: Excess water** |
| 9 | 0.125 | ✘ | ✘ | ✘ |
| 10 | 0.125 | ✘ | ✘ | ✘ |
| 11 | 0.125 | ✘ | ✘ | ✘ |
| 12 | 0.1 | ✔ | ✔ | ✔ |
| 13 | 0.1 | ✔ | ✔ | ✔ |

**Table 4 Summary of slurry behaviour against total weight of cuttlefish bone powder (bronze moulds 9 – 13)**

### *4.4.3 Dry mixture with added china clay (mixtures 14-18)*

China clay was added to the mixture to try to reduce the amount of fine casting plaster required to achieve setting. In mould 14, the amount of cuttlefish bone was increased above that in the successful mould 8, in the expectation that some China clay may compensate for this. In moulds 15 and 16 the relative amounts of China clay and cuttlefish bone are adjusted to achieve an acceptable balance between handling and setting characteristics, mould 17. In mould 18, a small amount of fine grog was introduced with a compensating increase in the amount of plaster.

| **Mixture** | **Total weight of cuttlefish bone powder (kg)** | **Criterion** | | |
|---|---|---|---|---|
| | | **1: Consistency** | **2: Setting time** | **3: Excess water** |
| 14 | 0.225 | ✔ | ✘ | ✘ |
| 15 | 0.2 | ✔ | ✘ | ✘ |
| 16 | 0.1 | ✘ | ✔ | ✔ |
| 17 | 0.15 | ✔ | ✔ | ✔ |
| 18 | 0.1 | ✔ | ✔ | ✔ |

**Table 5 Summary of slurry behaviour against total weight of the cuttlefish bone powder (bronze moulds 14 – 18)**

### *4.4.4 Other mixtures with added molochite, coarse cuttlefish bone and fine building sand (mixtures 19-32)*

Having established a number of successful formulations, other ingredients were introduced with a view to obtaining a series of formulations for heat resistance trials. An important factor influencing the selection of those experiments was the desire to introduce more cuttlefish bone powder to the formulation. Table 6 summarises the results of those trials according to the total weight of cuttlefish bone powder and the evaluation criteria.

| Mixture | Total weight of cuttlefish bone powder (kg) | Criterion | | |
|---|---|---|---|---|
| | | 1: Consistency | 2: Setting time | 3: Excess water |
| 19 | 0.167 | ✘ | ✘ | ✘ |
| 20 | 0.1 | ✔ | ✘ | ✘ |
| 21 | 0.1 | ✔ | ✔ | ✔ |
| 22 | 0.125 | ✔ | ✔ | ✔ |
| 23 | 0.125 | ✔ | ✔ | ✔ |
| 24 | 0.2 | ✔ | ✔ | ✔ |
| 25 | 0.2 | ✔ | ✔ | ✔ |
| 26 | 0.125 | ✘ | ✘ | ✘ |
| 27 | 0.1 | ✔ | ✘ | ✘ |
| 28 | 0.05 | ✔ | ✔ | ✔ |
| 29 | 0.125 | ✘ | ✘ | ✔ |
| 30 | 0.125 | ✔ | ✔ | ✔ |
| 31 | 0.1 | ✔ | ✔ | ✔ |
| 32 | 0.1 | ✔ | ✔ | ✔ |

**Table 6 Summary of slurry behaviour against total weight of cuttlefish bone powder (bronze moulds 19 – 32)**

## 4.5 Experiment I, Part II: The slurry technique for glass casting moulds

Figures 16 and 17 summarise the glass mould trials in terms of the dry ingredients and slurries respectively. The process of selection of formulations was informed by part I with the added constraint that certain other ingredients are traditional in glass moulds. The experiment was a continuation of the approach taken in Section 4.4.4 and Table 7 summarises the results again in terms of the selection criteria and also in terms of the total weight of cuttlefish bone.

| Mixture | Total weight of cuttlefish bone powder (kg) | Criterion | | |
|---|---|---|---|---|
| | | 1: Consistency | 2: Setting Time | 3: Excess water |
| 1 | 0.075 | ✔ | ✔ | ✔ |
| 2 | 0.1 | ✔ | ✔ | ✔ |
| 3 | 0.1 | ✔ | ✔ | ✔ |
| 4 | 0.075 | ✘ | ✔ | ✔ |
| 5 | 0.15 | ✘ | ✔ | ✔ |
| 6 | 0.15 | ✔ | ✔ | ✔ |
| 7 | 0.125 | ✘ | ✘ | ✘ |
| 8 | 0.1 | ✔ | ✔ | ✔ |
| 9 | 0.075 | ✔ | ✔ | ✔ |
| 10 | 0.15 | ✘ | ✔ | ✔ |
| 11 | 0.15 | ✘ | ✔ | ✔ |
| 12 | 0.1 | ✔ | ✔ | ✔ |
| 13 | 0.125 | ✘ | ✔ | ✘ |
| 14 | 0.1 | ✘ | ✔ | ✔ |
| 15 | 0.05 | ✘ | ✔ | ✔ |
| 16 | 0.1 | ✔ | ✔ | ✔ |
| 17 | 0.1 | ✔ | ✔ | ✔ |
| 18 | 0.15 | ✔ | ✘ | ✘ |
| 19 | 0.125 | ✘ | ✘ | ✔ |
| 20 | 0.1 | ✔ | ✔ | ✔ |
| 21 | 0.1 | ✘ | ✔ | ✔ |
| 22 | 0.05 | ✔ | ✔ | ✔ |
| 23 | 0.125 | ✘ | ✘ | ✔ |
| 24 | 0.15 | ✘ | ✘ | ✘ |
| 25 | 0.125 | ✘ | ✔ | ✔ |
| 26 | 0.1 | ✘ | ✔ | ✔ |
| 27 | 0.15 | ✘ | ✔ | ✔ |
| 28 | 0.15 | ✘ | ✘ | ✔ |
| 29 | 0.1 | ✔ | ✔ | ✔ |
| 30 | 0.125 | ✘ | ✔ | ✔ |
| 31 | 0.125 | ✔ | ✔ | ✔ |
| 32 | 0.125 | ✔ | ✔ | ✔ |
| 33 | 0.125 | ✔ | ✔ | ✔ |
| 34 | 0.05 | ✔ | ✔ | ✔ |
| 35 | 0.1 | ✔ | ✔ | ✔ |
| 36 | 0.15 | ✔ | ✔ | ✔ |
| 37 | 0.1 | ✔ | ✔ | ✔ |

**Table 7 Summary of slurry behaviour against total weight of cuttlefish bone powder (all glass moulds)**

### 4.6 Summary

From 32 trial bronze investment casting moulds, only 14 successfully met the evaluation criteria. Of the 37 glass trial moulds only 19 moulds were successful. The next stage was to evaluate how the successful formulations performed under the thermal and mechanical stresses of the casting processes.

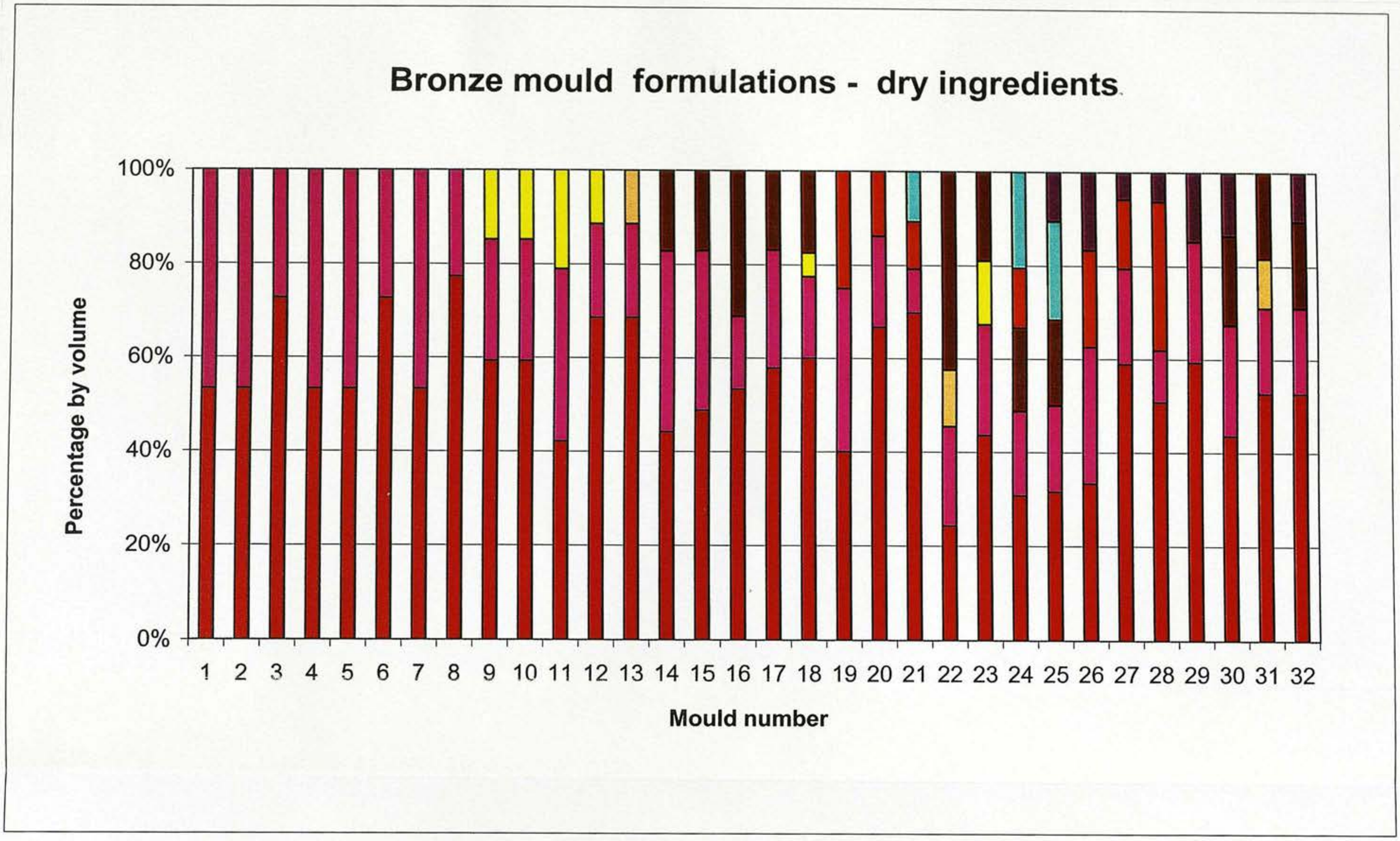



**Fig. 14 Bronze mould formulations – dry ingredients**

**KEY**

Fine casting plaster

Fine cuttlefish bone powder

Fine grog (sieve mesh 85 and under)

Coarse grog (sieve mesh 5 and under)

China clay

Molochite

Coarse cuttlefish bone

Fine building sand

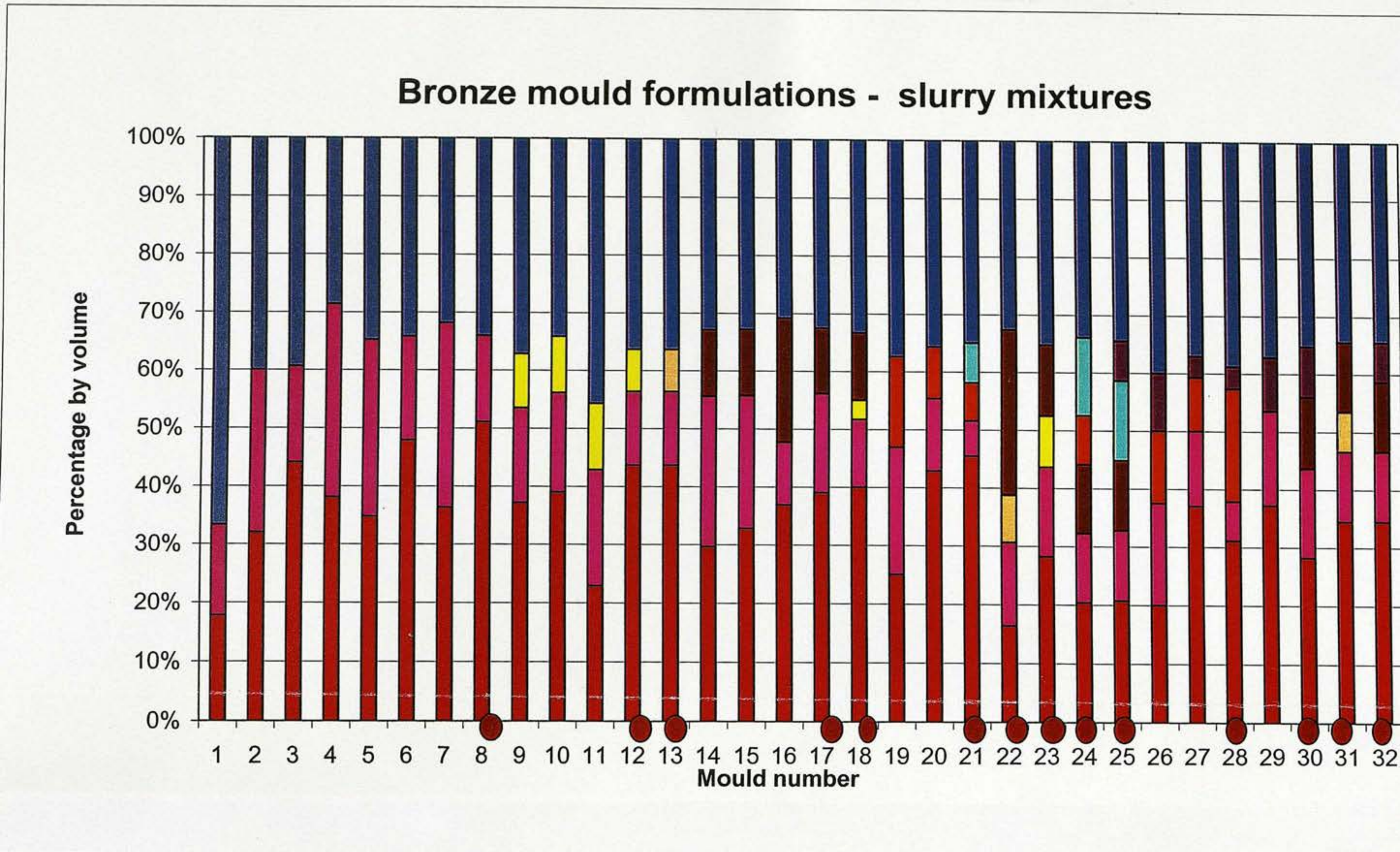



**Fig. 15 Bronze mould formulations – slurry mixtures**

**KEY**

Fine casting plaster

Fine cuttlefish bone powder

Fine grog (sieve mesh 85 and under)

Coarse grog (sieve mesh 5 and under)

China clay

Molochite

Coarse cuttlefish bone

Fine building sand

Water

Denotes successful formulation

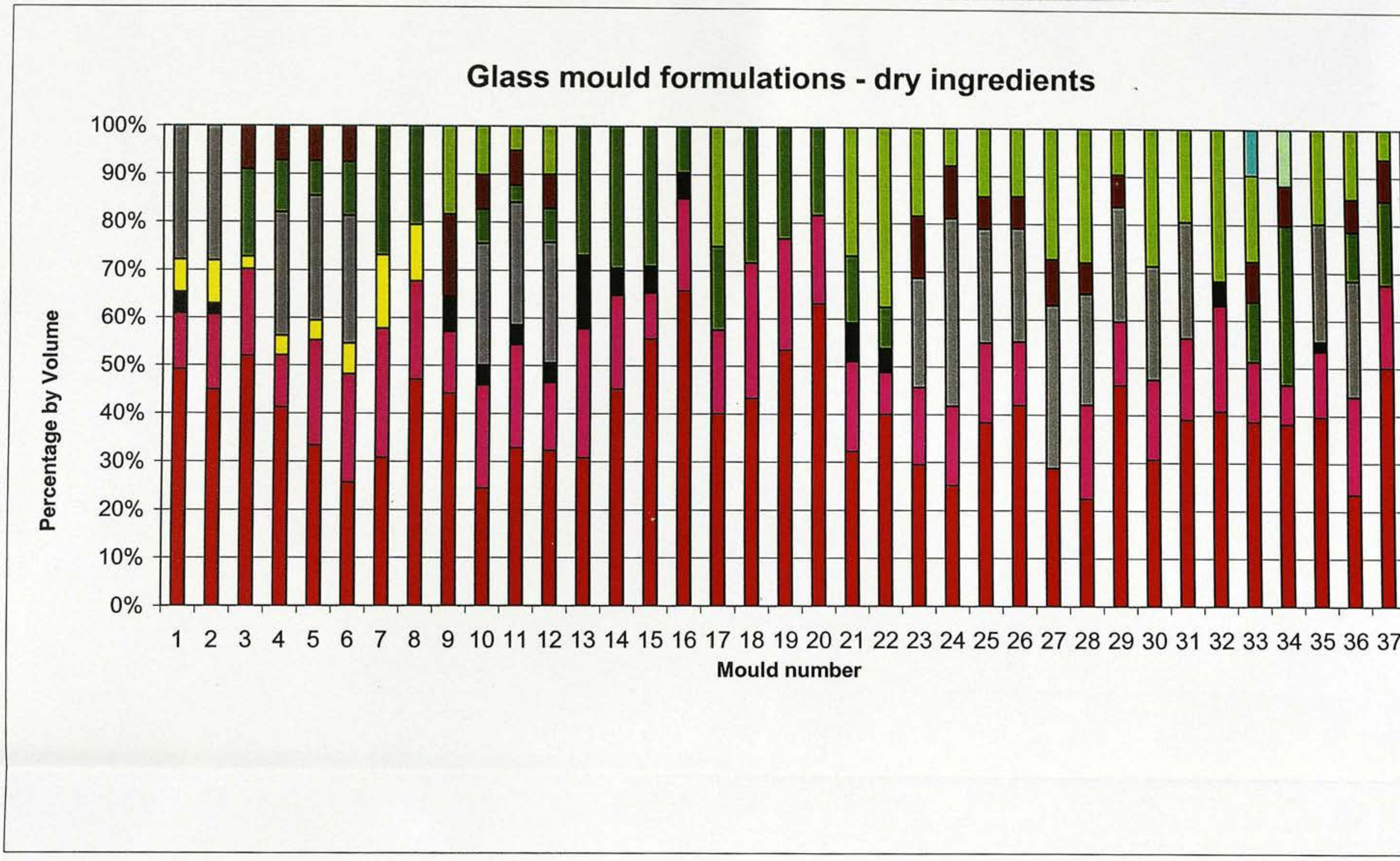



**Fig. 16 Glass mould formulations – dry ingredients**

**KEY**

Fine casting plaster

Fine cuttlefish bone powder

Silver sand

Fine grog (sieve mesh 85 and under)

Vermiculite

Flint

China clay

Glass old mould

Coarse cuttlefish bone

Glass fibre

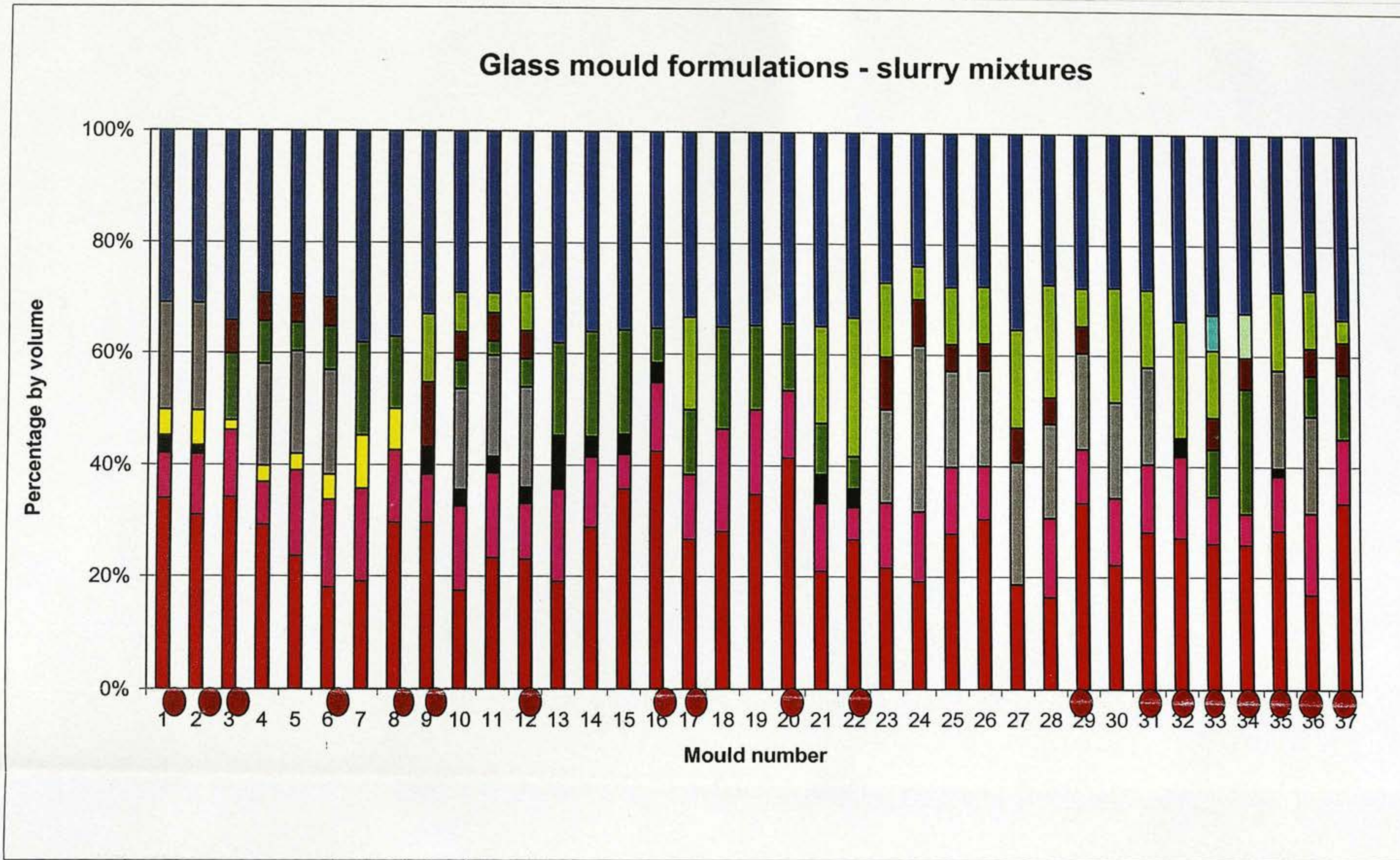



**Fig. 17 Glass mould formulations – slurry mixtures**

**KEY**

Fine casting plaster

Fine cuttlefish bone powder

Silver sand

Fine grog (sieve mesh 85 and under)

Vermiculite

Flint

China clay

Glass old mould

Coarse cuttlefish bone

Glass fibre

Water

Denotes successful formulation

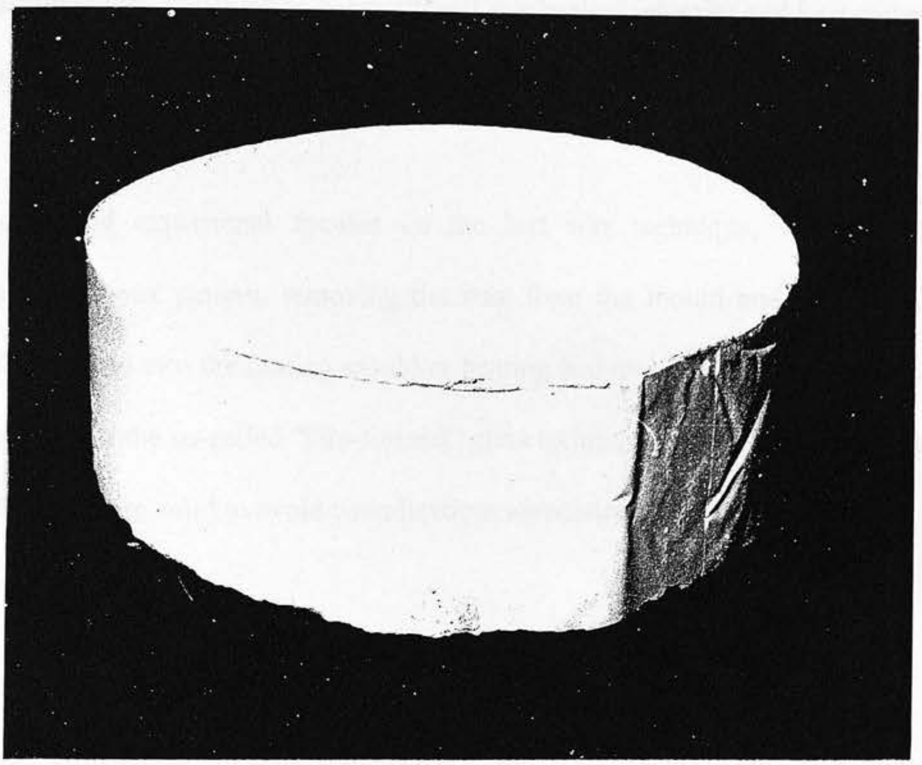


**Plate 9 Typical form used for assessment of moulding material**

# Chapter 5. EXPERIMENT II: HEAT RESISTANCE OF BRONZE AND GLASS CASTING MOULDS

## 5.1 Introduction.

The handling experiments described in Chapter 4 resulted in the selection of a series of candidate formulations for investment casting moulds for bronze and for glass respectively. These experiments, however, only establish that the formulation can be handled and sets acceptably. Another series of experiments is required to determine if the formulation has sufficient mechanical integrity and heat resistance to perform its function.

This second experiment focuses on the lost wax technique, which involves investing a wax pattern, removing the wax from the mould and either pouring molten bronze into the casting mould or heating and melting glass into the casting mould, using the so-called "kiln-formed" glass technique. All of the test sculptures made here were solid to avoid complications associated with the use of cores.

The criteria used here to determine the quality of the formulations were:

i. The mechanical integrity of the mould.

ii. The aesthetic effect of the mould on the bronze or glass sculpture.

The integrity requirement of a mould is not simple to evaluate. Clearly, during pouring or filling, cracking can be tolerated to a limited extent only, and then only for bronze casting where flash and the cast piece can be relatively easily removed. It is also important that the mould can be broken to release the piece without causing any damage to it. Finally, the mould has to be resistant to the firing process.

## 5.2 Casting processes

As illustrated in Chapter 2 (Fig. 3), the processes used for bronze and glass have some common elements, and some which differ. Here, we concentrate on the aspects of the processes which can result in failure to produce an acceptable piece.

### *5.2.1 Sculpture moulds*

Lost-wax casting is basically simple. Small sculptures can be cast solid but, in the case of large works, it is necessary to make hollow castings fashioned in wax around a core of refractory materials. The wax model (including the cores, if used) is itself surrounded by a mould of refractory material, called investment or ludo, which must be plastic enough to take a good imprint of the wax. The mould is then heated to about 650°C for bronze moulds or to about 100°C for glass moulds until the wax melts and drains out or burns away, leaving a cavity into which the molten bronze or glass replaces the lost wax.

### *5.2.2 The wax and its preparation.*

Wax is used often but not exclusively, to make the pattern for both bronze and glass sculpture. From early times, beeswax has been used for this purpose, but a number of modern formulations are now available. These are normally synthetic petroleum-based compounds, and this work used a mixture of two parts of the strong, but brittle, earth wax, to one part of the soft, synthetic beeswax (paraffin wax). There are many ways of developing the wax model and an even thickness, about 3mm for small works, increasing as size increases, is required when using cores. Wax runners and risers are also required for complex shapes, to act as feeds for the bronze or glass and escape tubes for the gases.

In this work, the test pieces were simple and solid and the wax patterns were replicas of the final piece. The method adopted was to model the pattern in clay, and then make a two-part mould around the clay model. The mould was then used to cast the wax into, in order to obtain the sacrificial pattern.

### *5.2.3 Investment moulds: bronze and glass*

The completed wax model has to be covered with the final mould, the investment, the formulation of which is the subject of this work. Notwithstanding the considerations described in chapter 4, the materials used for investment (and for any core) must be refractory and suitable for application on wax, porous and strong enough to withstand the pressure of molten bronze or glass, and able to withstand the thermal effects of the firing and casting processes. Normally, the materials used are plaster of Paris, brick powder or pulverized ceramic piping (grog) or other refractories. The thickness of the mould depends on the size of the sculpture.

### *5.2.4 Wax removal and firing*

The completed mould must be baked to make sure that wax and other moisture are removed, so as to avoid gases building up during casting thereby causing flaws in the casting or failure of the mould. The bronze moulds were placed on two rows of bricks, with the pouring gate facing downwards, to drain and collect the melting wax. The first part of the firing process involved gradual heating during which the wax melted and drained out (Plates 10 and 11). For glass moulds, this was achieved by a separate steaming process, whereas, with bronze moulds, it was integral with the firing of the mould.

For bronze moulds, the temperature was eventually held at 650°C, at which temperature any residual wax burns away and unbound water evaporates. This heating and holding took a total of 8 hours, after which the furnace was left to cool down slowly to room temperature and the mould removed from the furnace. Firing of the glass moulds was integral with the casting process and is described in Section 5.2.6.

### *5.2.5 Pouring the molten bronze*

After removal from the firing furnace, the mould was reinforced by being buried in damp sand for about three quarters of its height. During this process great care was taken to prevent grains of sand or dust from entering the mould through the pouring gate (Plates 12 and 13). At the same time the crucible was heated up to 1100-1200°C to melt the bronze which was poured quickly into the mould (Plates 14 and 15).

### *5.2.6 Kiln-formed glass technique*

Glass casting differs from bronze casting, in a number of ways. As mentioned above, the same procedure was used to melt and remove the wax originals by heating the investment moulds. However, the method used to melt the glass was much simpler. The required temperature is this time only about 850°C. Crushed glass was put into a cup at the top of the mould and the kiln temperature was raised to the melting point, at which stage the glass flows into the mould cavity. Because this process happens inside the kiln itself (Plate 16), the moulds require a greater mechanical integrity, as it is not possible to support them with sand as is the case for bronze casting. Once the molten glass has filled the casting spaces, it is necessary to leave the moulds for many hours to cool very gradually, in order that the glass does not crack or craze. For the glass pieces made here, cooling times of over 13 hours were used.

The main differences between glass and bronze casting may be summarised thus: Bronze moulds are subjected to much greater temperatures and the act of filling the mould by rapid pouring in of liquid metal results in high thermal and mechanical stresses. On the other hand, the mould is supported against bursting by a sand backing. Glass casting is a much gentler process involving lower temperatures and lower rates of heating and cooling, although the mould must be strong enough to hold together without support. Fig. 18 and Fig. 19 show the relative time-temperature cycles seen by the two respective processes, and the processes themselves are illustrated schematically in Fig. 3.

### 5.3 The heat resistance experiments

The heat resistance experiments consisted essentially of exposing the candidate mould materials to the relevant casting process and observing the performance of the mould. A set of three different bronze patterns and two different glass patterns were designed. One further bronze mould was specifically designed to compare the surface reproduction capabilities of the best bronze formulation developed in this work with the conventional one used in ECA. The designs are summarised in Fig. 20 The results of each of these experiments are described in the following sections. More detailed observations can be found in Appendix 1 (for bronze moulds) and Appendix 2 (for glass moulds).

### *5.3.1 Bronze mould heat resistance*

Detailed criteria for bronze mould performance were devised as follows:

Criterion 1: There should be no gross cracking or breakage during firing.

Criterion 2: The mould should not burst during pouring

Criterion 3: The surface of the bronze should not contain excessive flash (indicative of excessive internal surface cracking)

Criterion 4: It should be possible to remove the mould easily after solidification.

| Mould number | Criterion | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Bm8 | ✘ | ✘ | ✘ | ✔ |
| Bm12 | ✘ | ✘ | ✘ | ✔ |
| Bm13 | ✘ | ✘ | ✘ | ✔ |
| Bm17 | ✘ | ✘ | ✘ | ✔ |
| Bm18 | ✘ | ✘ | ✘ | ✔ |
| Bm21 | ✘ | ✘ | ✘ | ✔ |
| Bm22 | ✔ | ✔ | ✔ | ✔ |
| Bm23 | ✔ | ✘ | ✔ | ✔ |
| Bm24 | ✔ | ✔ | ✔ | ✔ |
| Bm25 | ✔ | ✔ | ✔ | ✔ |
| Bm28 | ✔ | ✘ | ✘ | ✔ |
| Bm30 | ✔ | ✘ | ✘ | ✔ |
| Bm31 | ✔ | ✘ | ✘ | ✔ |
| Bm32 | ✔ | ✘ | ✘ | ✔ |

**Table 8 Summary of heat resistance of bronze moulds**

All 14 of the candidate bronze formulations were made into moulds for the casting mould B1, and the results are shown in Table 8.

| **Mould number** | **Criterion (p79)** | | | |
|---|---|---|---|---|
| | **1** | **2** | **3** | **4** |
| Bm22 | ✔ | ✔ | ✔ | ✔ |
| Bm24–1 | ✔ | ✔ | ✔ | ✔ |
| Bm24–2 | ✔ | ✔ | ✔ | ✔ |
| Bm24–3 | ✔ | ✔ | ✔ | ✔ |
| Bm24–4 | ✔ | ✔ | ✔ | ✔ |
| Bm24–5 | ✔ | ✔ | ✔ | ✔ |
| Bm24–6 | ✔ | ✔ | ✔ | ✔ |
| Bm25–1 | ✔ | ✔ | ✔ | ✔ |
| Bm25–2 | ✔ | ✔ | ✔ | ✔ |

**Table 9 Further examination of heat resistance of bronze moulds 22, 24 and 25**

On the basis of the results, formulations Bm.22, Bm.24, and Bm.25 were selected for further testing with casting mould B2 and the results are shown in Table 9. Mould 24 was selected for more intensive testing because of the good quality surface it had produced in the previous tests.

Bronze mould 24 (Bm24) was further tested with the larger casting mould B3 and compared with the existing Edinburgh College of Art bronze investment mould material. The results are shown in Table 10.

| Mould number | Criterion (p79) | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Bm24 | ✔ | ✔ | ✔ | ✔ |
| Bm24 | ✔ | ✔ | ✔ | ✔ |
| Bm24 | ✔ | ✔ | ✔ | ✔ |
| Bm24 | ✔ | ✔ | ✔ | ✔ |
| Bm24 | ✔ | ✔ | ✔ | ✔ |
| ECA mould | ✔ | ✘ | ✘ | ✘ |

**Table 10 Heat resistance of bronze mould formulation 24 compared with conventional Edinburgh College of Art bronze mould**

### *5.3.2 Glass mould heat resistance*

Detailed criteria for glass mould performance were devised as follows:

Criterion 1: There should be no gross cracking or breakage during kiln-forming.

Criterion 2: The surface of the glass should not contain excessive flash (indicative of excessive internal surface cracking).

Criterion 3: It should be possible to remove the mould easily after solidification.

All 19 of the candidate glass formulations were made into moulds for the casting mould G1 and the results are shown in Table 11.

On the basis of these results, formulations Gm6, Gm12, Gm29 and Gm36 were selected for further testing with casting mould G2 and the results are shown in the following Table 12.

| Mould number | Criterion (p81) | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Gm1 | ✘ | ✔ | ✔ |
| Gm2 | ✘ | ✔ | ✔ |
| Gm3 | ✘ | ✘ | ✘ |
| Gm6 | ✔ | ✔ | ✔ |
| Gm8 | ✘ | ✘ | ✘ |
| Gm9 | ✘ | ✘ | ✘ |
| Gm12 | ✔ | ✔ | ✔ |
| Gm16 | ✘ | ✘ | ✘ |
| Gm17 | ✘ | ✘ | ✘ |
| Gm20 | ✘ | ✘ | ✘ |
| Gm22 | ✘ | ✘ | ✘ |
| Gm29 | ✔ | ✔ | ✔ |
| Gm31 | ✘ | ✘ | ✘ |
| Gm32 | ✘ | ✘ | ✘ |
| Gm33 | ✘ | ✔ | ✔ |
| Gm34 | ✔ | ✘ | ✘ |
| Gm35 | ✔ | ✘ | ✔ |
| Gm36 | ✔ | ✔ | ✔ |
| Gm37 | ✘ | ✘ | ✘ |

**Table 11 Heat resistance of glass moulds**

| Mould number | Criterion (p81) | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Gm 6 | ✔ | ✔ | ✔ |
| Gm 12 | ✔ | ✔ | ✔ |
| Gm 29 | ✔ | ✔ | ✔ |
| Gm 37 | ✔ | ✔ | ✔ |

**Table 12 Heat resistance of glass moulds 6, 12, 29 and 36**

## 5.4 Conclusion

From 14 bronze investment casting moulds have been tested in the bronze heat resistance casting mould B1, B2 and B3, as the result only bronze mould formulation 22, 24 and mould 25 were very successful. On the other, 19 glass investment casting moulds have been tested in glass heat resistance casting mould G1 and G2. Therefore, only glass mould formulation 6, 12, 29 and 36 were very successful.

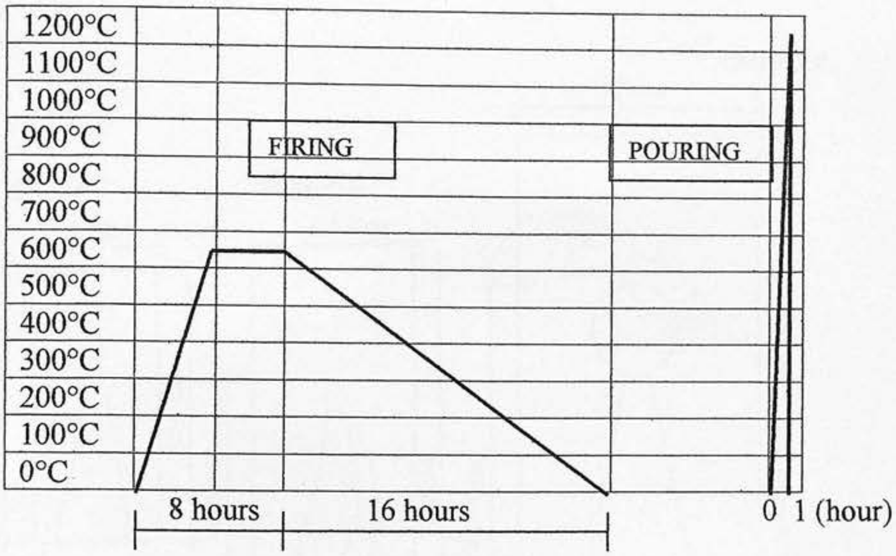



**Fig. 18 Schematic thermal profile for firing and pouring the bronze investment casting moulds**

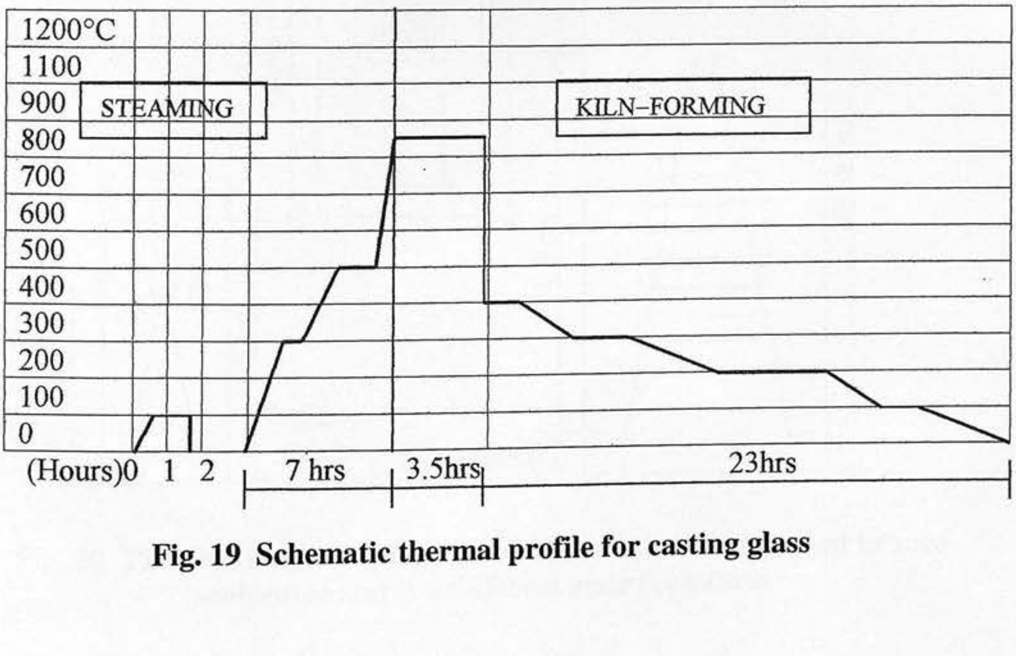



**Fig. 19 Schematic thermal profile for casting glass**

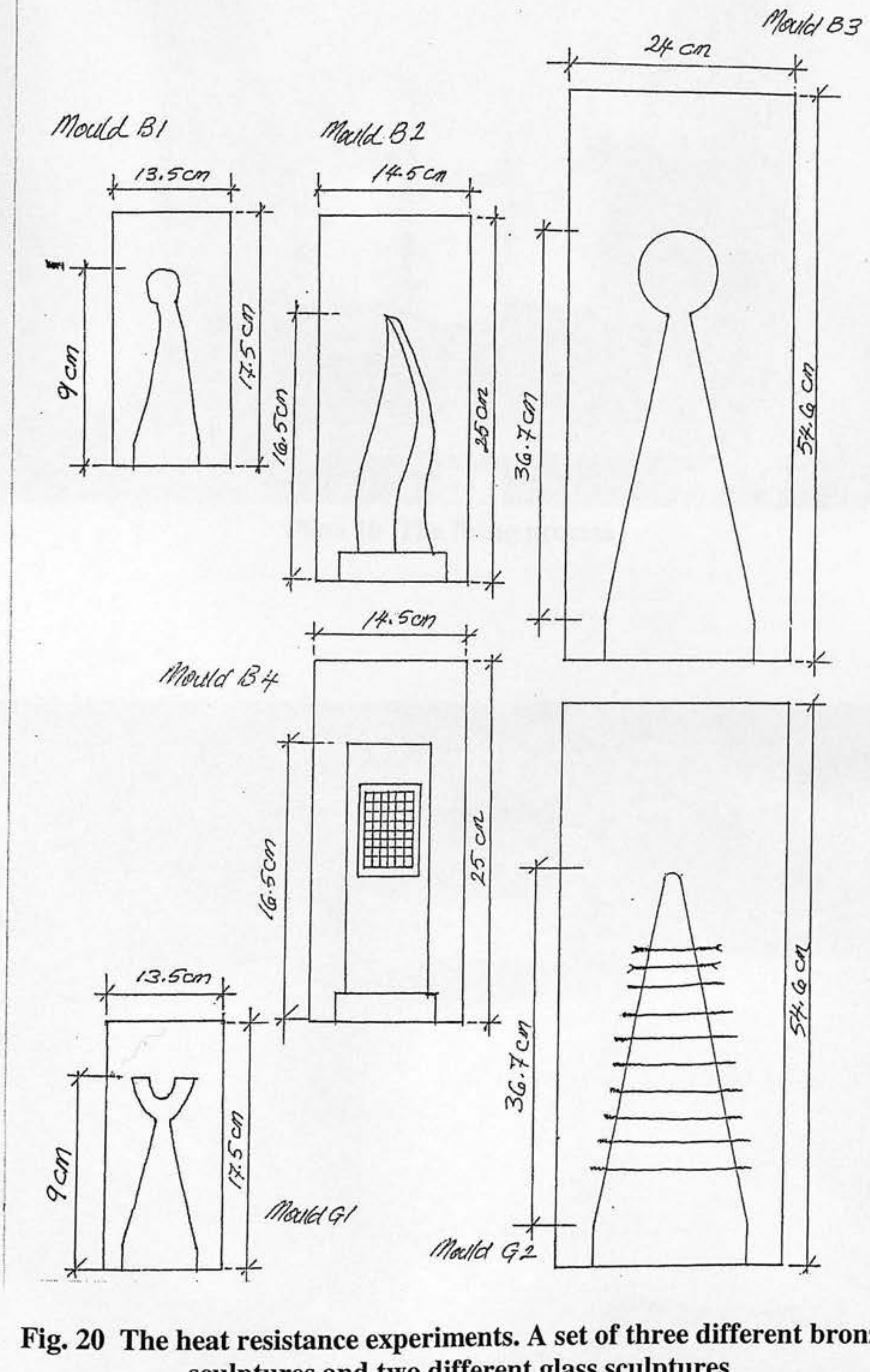



**Fig. 20 The heat resistance experiments. A set of three different bronze sculptures and two different glass sculptures**

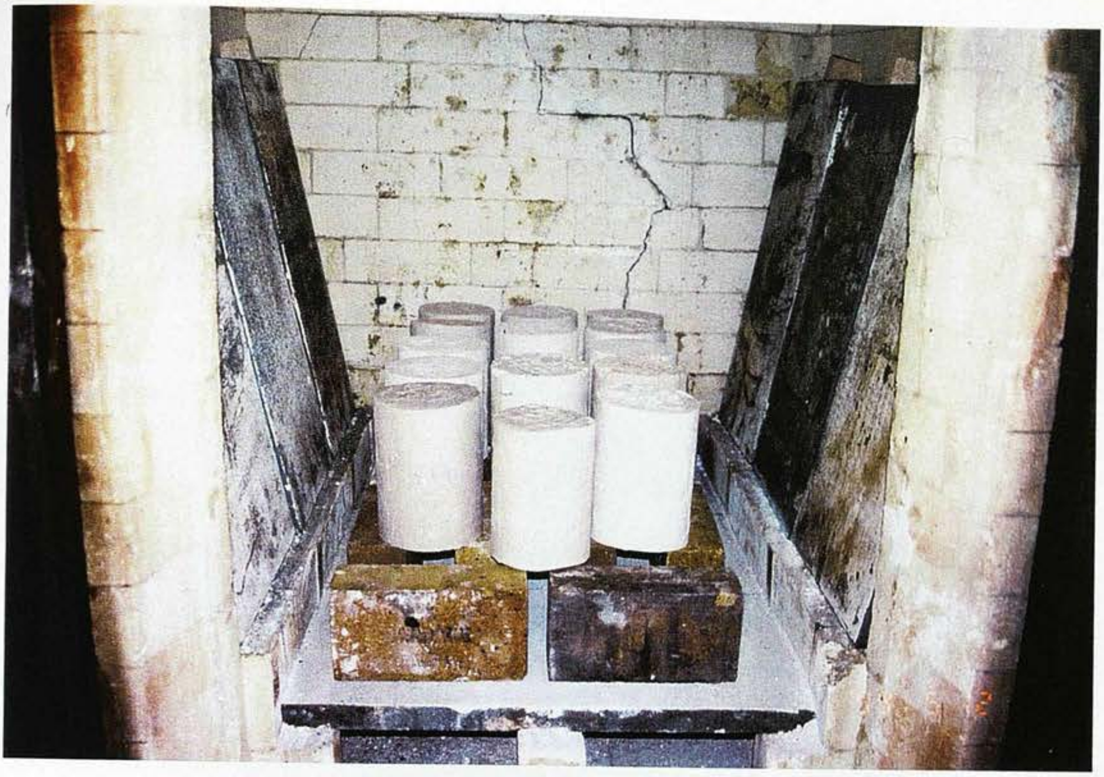


**Plate 10 The firing process**

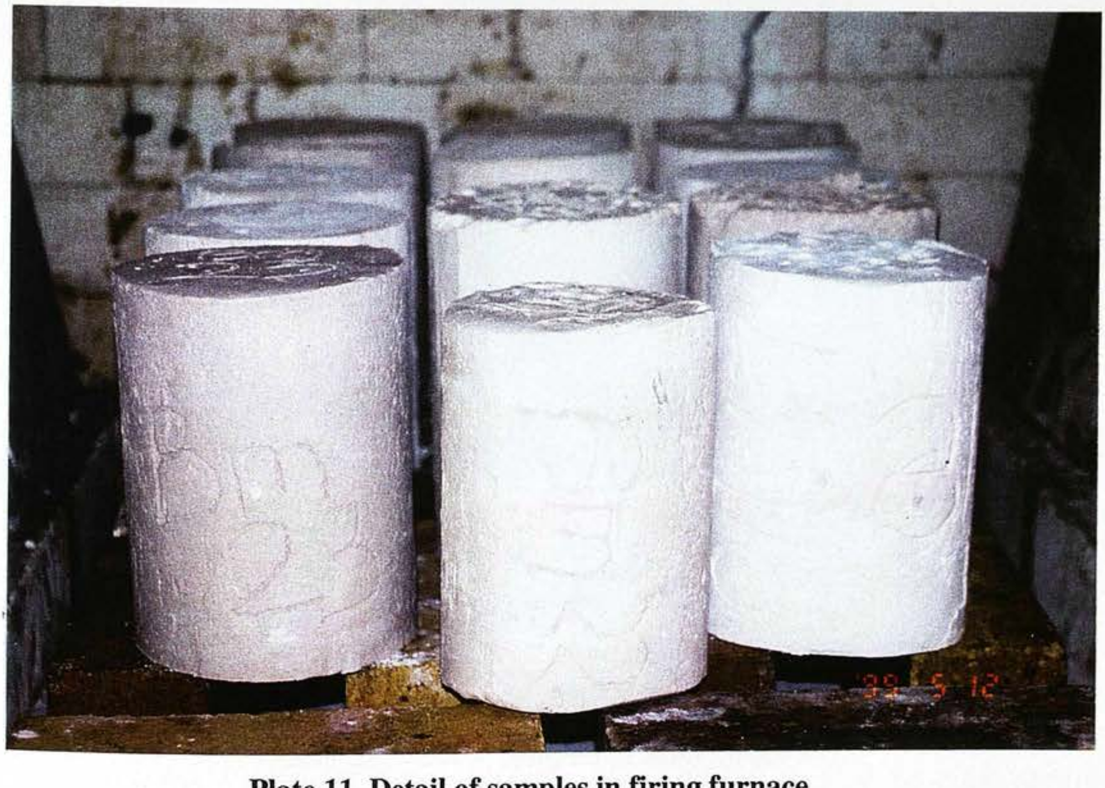


**Plate 11 Detail of samples in firing furnace**

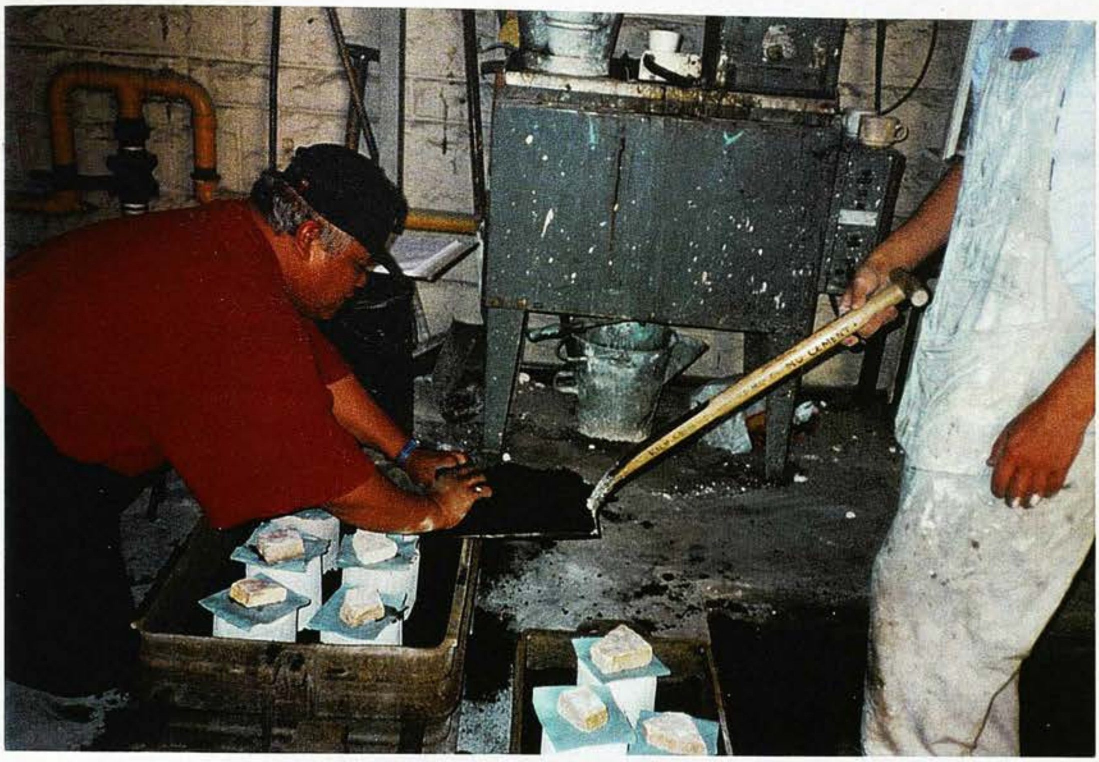


**Plate 12  Moulds being buried in damp sand**

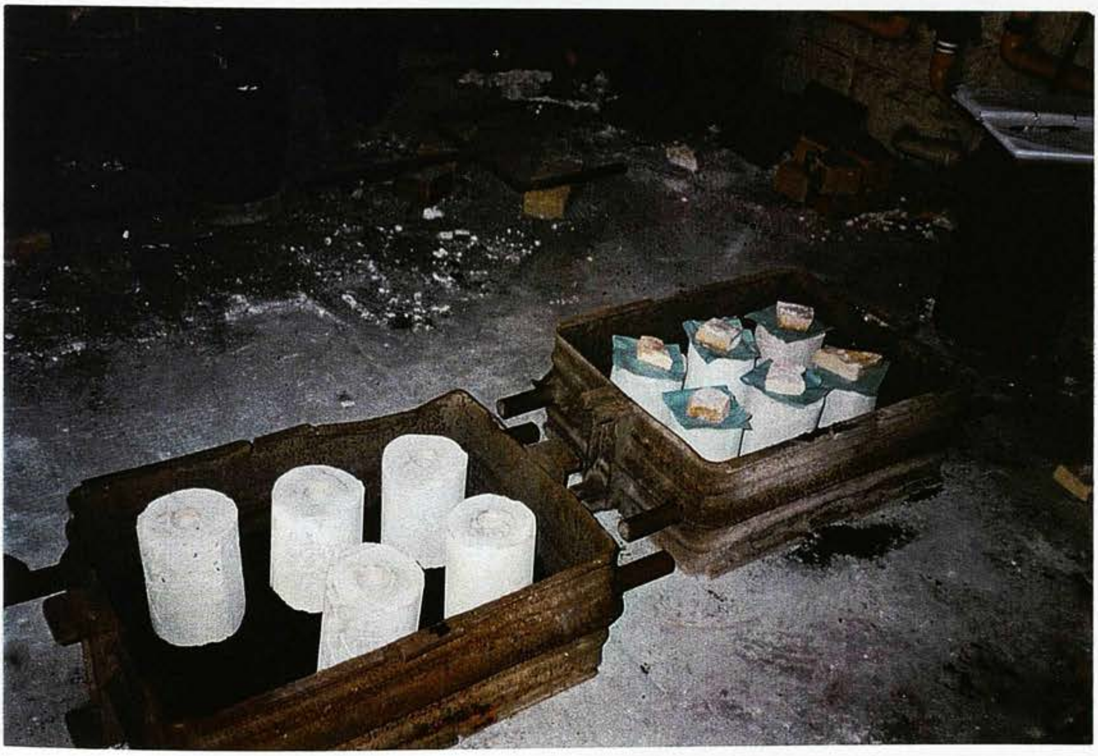


**Plate 13 Detail of samples in sand forms**

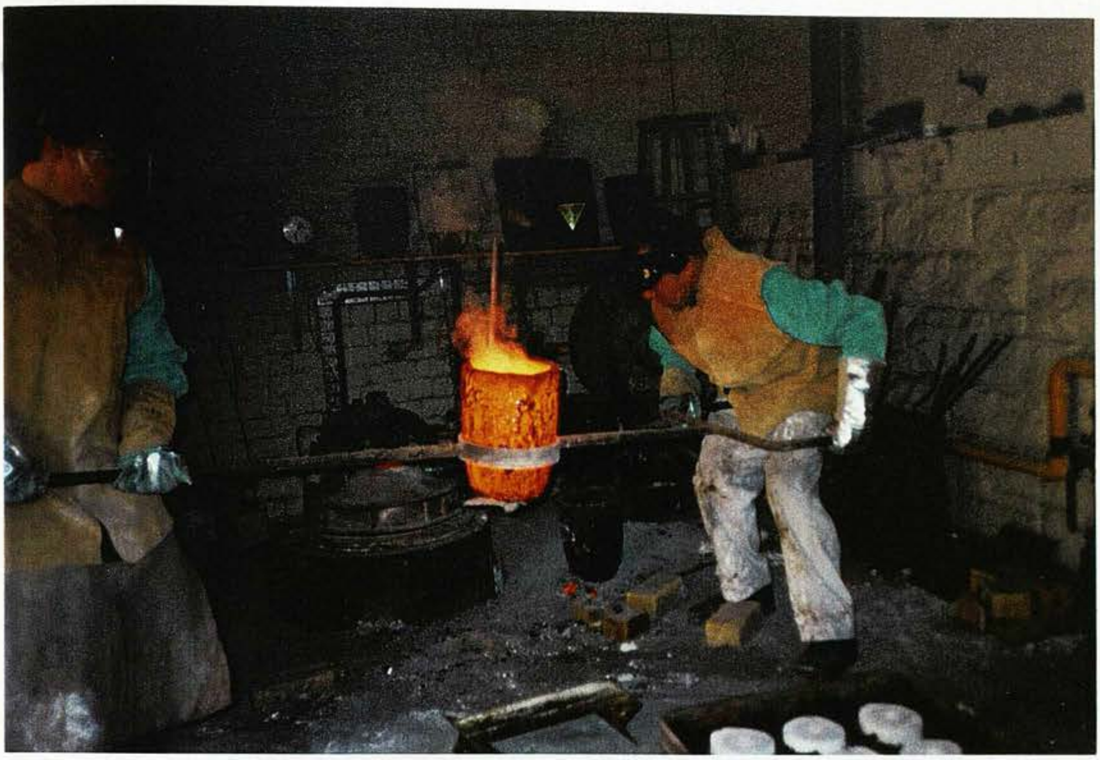


**Plate 14 Pouring the molten bronze into investment casting moulds**

**Plate 15 Samples after pouring of bronze**

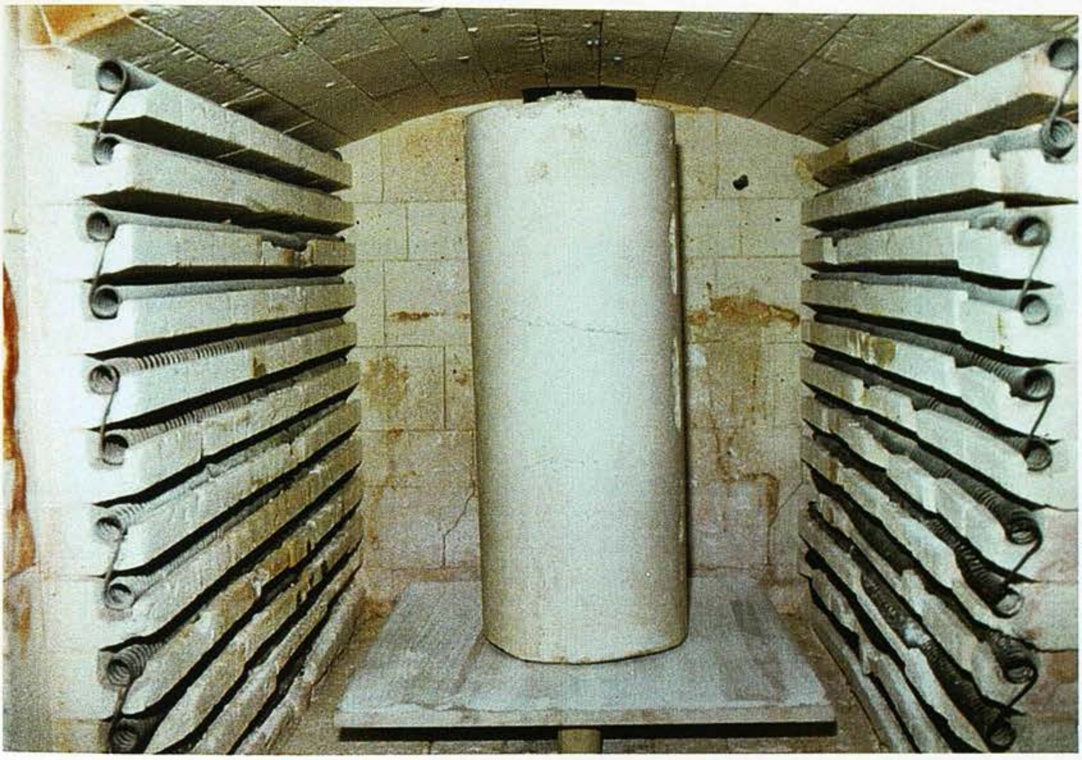


**Plate 16 Glass investment casting mould in the kiln ready to fire**

# Chapter 6. MICROSTRUCTURE DRAWING AS AN AID TO UNDERSTANDING MOULD BEHAVIOUR

## 6.1 The Purpose of Microstructure Drawing

The main purpose of the microstructure drawing is to visualize the behaviour of the mould formulations in a way that can be understood by other practitioners, to whom the research is directed. The drawings are used in the next chapter as an aid to interpreting the results of the experiments in terms of:

i. Handling behaviour

ii. Hardening behaviour

iii. Mechanical behaviour under the casting stresses

In order to develop the visualisation, a series of micrographs of the components of the dry mix and of the hardened moulds were taken (Plates 17–29). These micrographs were used to develop a symbolic language which expresses the size and shape of the dry ingredients. The symbols were then proportioned in relation to the amounts of the ingredients in the dry mix and pictures prepared of the slurries including the added water. Finally, the hydration of the plaster was represented by drawing cross-links between the plaster particles to develop a picture of the hardened mould material. The whole process is illustrated schematically in Fig.21 and the following sections illustrate each stage of the process using examples.

## 6.2 Micrographs of the components

The scanning electron microscope images are shown in Plates 17–29. The largest size of the materials mixture can be seen from microscopic images (scanning electron microscope ) and are:

Fine casting plaster – 160μm (Plate 17), fine cuttlefish bone powder – 800μm (Plate 18), fine grog – 270μm (Plate 19), coarse grog –1500μm (Plate 20), China clay – 20μm (Plate 21), molochite – 80μ (Plate 22), coarse cuttlefish bone – 5000μm (Plate 23), fine building sand 350μm (Plate 24), silver sand – 500μm (Plate 25), vermiculite 5000μm (Plate 26), flint – 30μm (Plate 27), glass old mould – 50μm (Plate 28) and finally, glass fibre – 5000μm (Plate 29).

As an example, Fig. 22 shows that the particle size of the fine casting plaster shown in Plate 17 varies between 160$\mu$m and about 5$\mu$m.

### 6.3 The Key

Each component has a range of sizes and an approximate average size was determined and used to develop the key. A symbol was chosen to reflect the approximate size and shape of the component Fig.23.

### 6.4 Proportioning the mixtures

The proportions of dry ingredients on a volumetric basis were then used to determine what proportion of a grid of area 100 square cm would be occupied by each component. For components which had a wide range of sizes, more than one size symbol was used e.g. table 13 shows the proportioning of the dry ingredients in bronze mould 12. The 10,000 square mm grid was divided into 2,500 2mm×2mm units (Fig. 24) and the number of units to be occupied by each size of each component was calculated using a scale whereby 100 microns actual size is represented by 2mm (corresponding to an effective magnification of 20×) (Fig.

25). Using the information generated by Table 13, a drawing was made of the number of units occupied by each ingredient and their symbolic representation for bronze mould 12 (Fig. 26).

| Mould | Component | Particle Size | Number of symbols involved |
|---|---|---|---|
| Bronze 12 | F.c.p 68.6% | 160μm | 160μm ≡ 3.2mm = size of symbol<br><br>Total area to be occupied = $0.686 \times 10000 = 6860mm^2$<br><br>Number of F,c.p symbols required = $6860/3.2^2$ = **670 symbols** |
| | F.ctb. p 20% | S1 800μm<br>S2 400μm<br>S3 200μm | 800μm ≡ 16 mm = size of symbol S1<br>400μm ≡ 8 mm = size of symbol S2<br>200μm ≡ 4 mm = size of symbol S3<br><br>Total area to be occupied = $0.2 \times 10000 = 2000$ mm$^2$<br><br>Half area is occupied by large size and quarter each of the smaller sizes, so:<br><br>Number of S1 symbols required = $1000/16^2$ = **4 symbols**<br>Number of S2 symbols required = $500/8^2$ = **8 symbols**<br>Number of S3 symbols required = $500/4^2$ = **31 symbols** |
| | F.grog 11.4% | 270μm | 270μm ≡ 5.4 mm = size of symbol<br><br>Total area to be occupied = $0.114 \times 10000 = 1140mm^2$<br><br>Number of F,grog symbols required = $1140/5.4^2$ = **39 symbols** |

**Table 13 Proportioning of the dry ingredients in bronze mould 12**

## 6.5 Preparing the slurry drawings

Once the required number of symbols was known, along with their sizes and distribution (Fig.27 a and b), the dry mix was "diluted" by expanding the 10cm×10cm grid according to the volumetric ratio of water to dry ingredients. For the case of the bronze mould 12 described above, the total volume of dry ingredients is 700 ml, to which 400 ml of water was added (refer back to the bar chart in Chapter 4). Therefore one dimension of the grid was expanded by a factor of 1100/700 to give a rectangular grid of 15.7cm × 10cm into which the required number of symbols were drawn. The grid was then "trimmed back" to square, yielding a picture of the slurry with the proportions of dry ingredients to water shown, and the dry ingredients scaled with respect to each other (Fig. 27 c).

## 6.6 Preparing the set mould drawings

Once a picture of the slurry had been obtained, a picture of the set mould was generated simply by drawing cross links between the plaster particles (Fig. 28).The entire drawing technique was repeated on several formulations (Fig. 29, 30, 31, 32, 33 and 34) until the entire process became intuitive and the slurry and set mould could be drawn freehand directly from the formulation. At this point, it was considered that a visual model of the formulation had been developed.

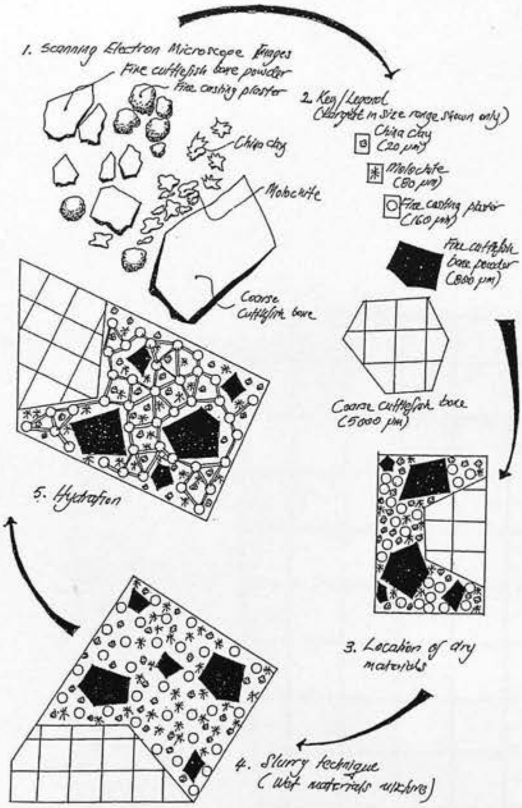



**Fig. 21 Diagrammatic representation of model development**

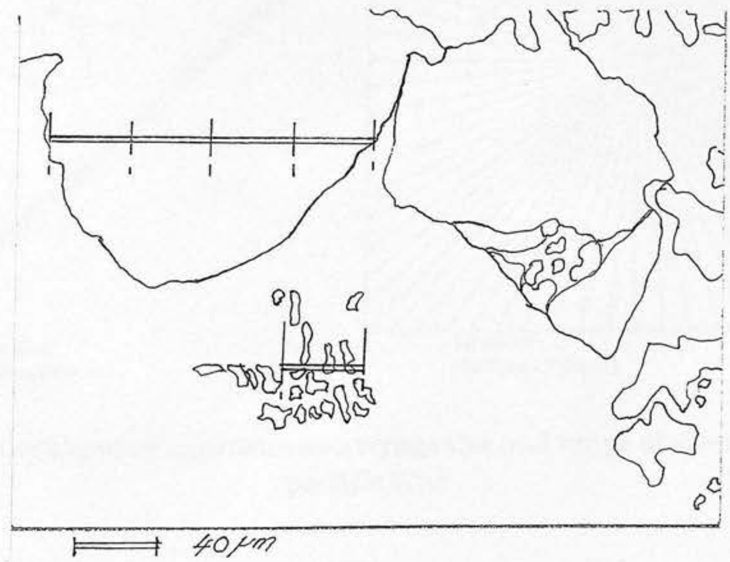



**Fig. 22 The particle size of the fine casting plaster**

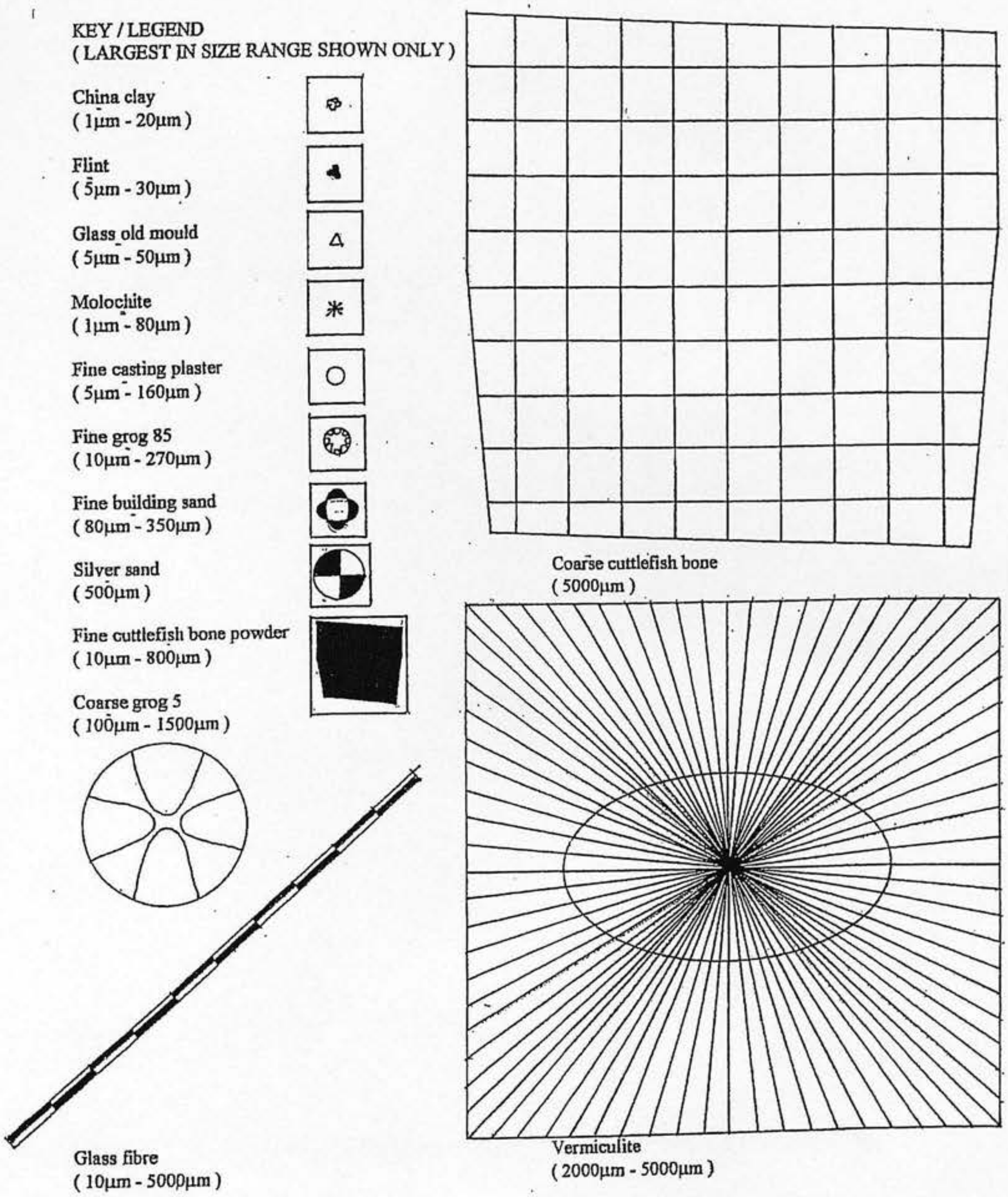



**Fig. 23 Key showing approximate average size and range of sizes for each particle type**

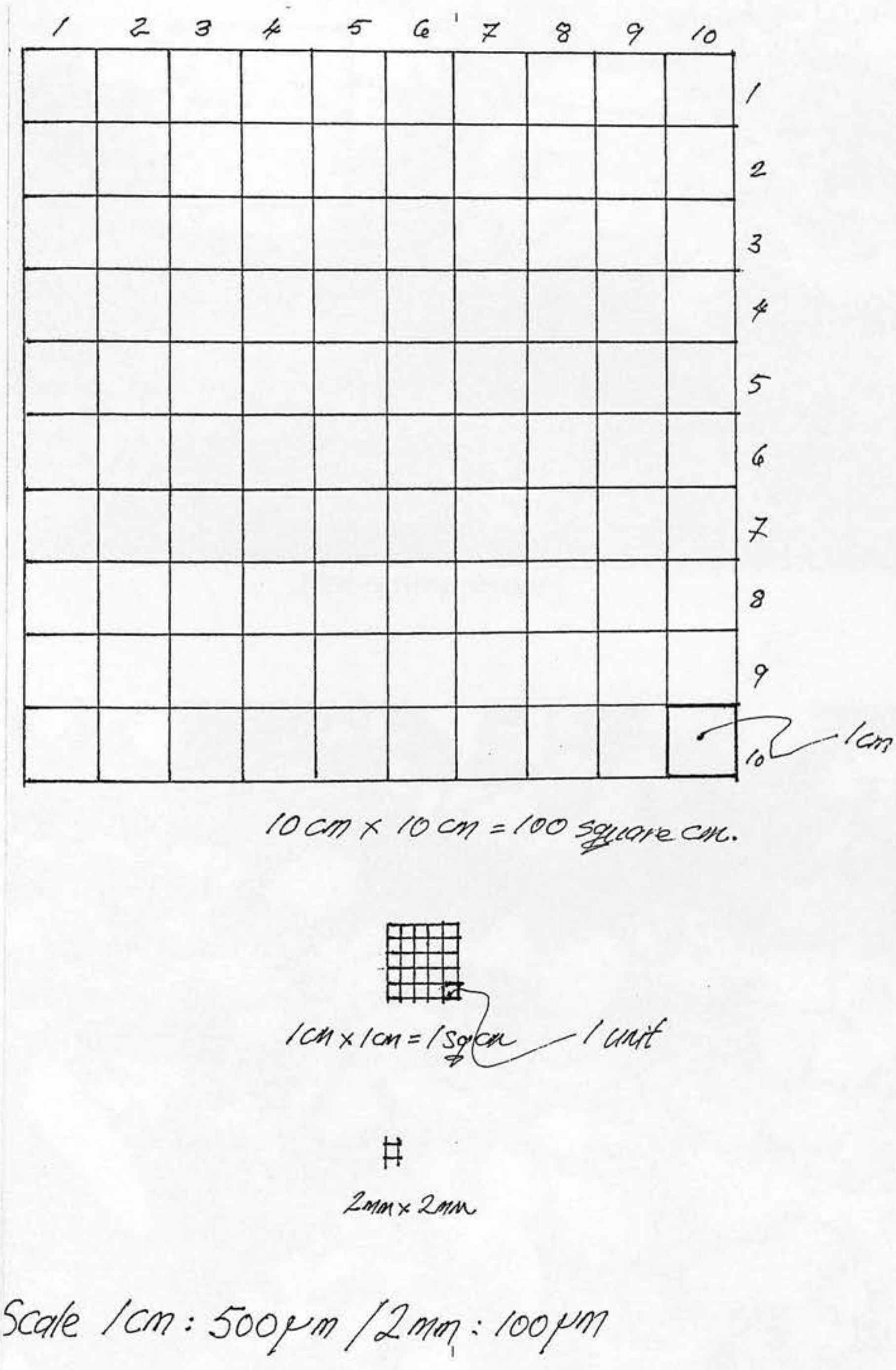
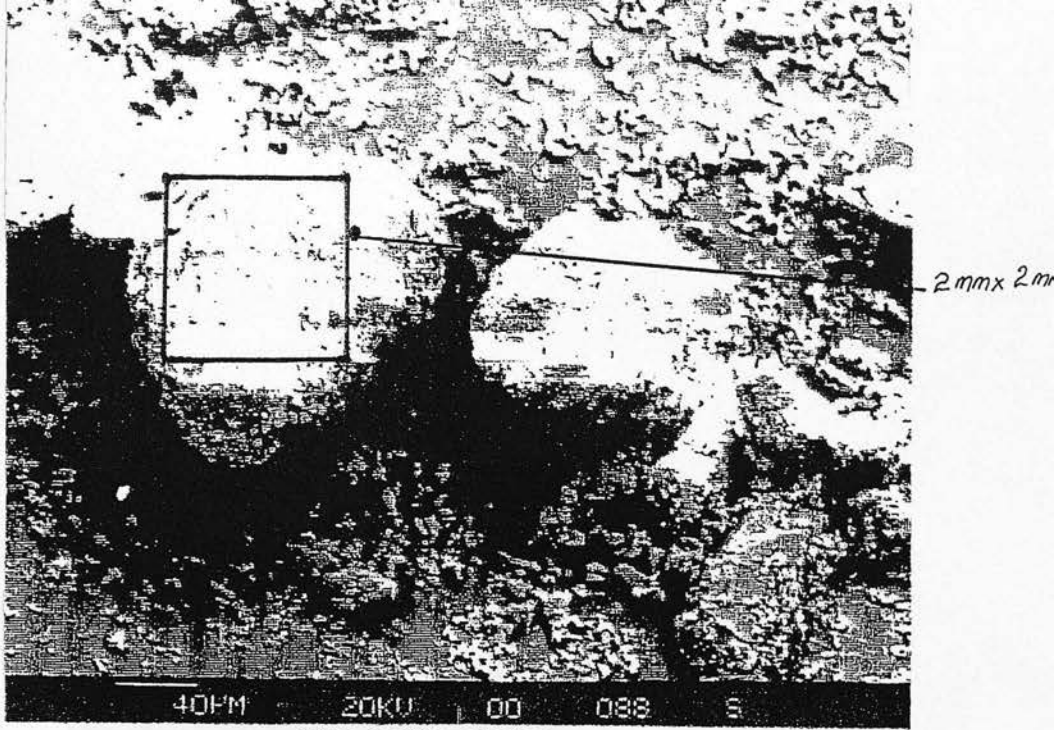
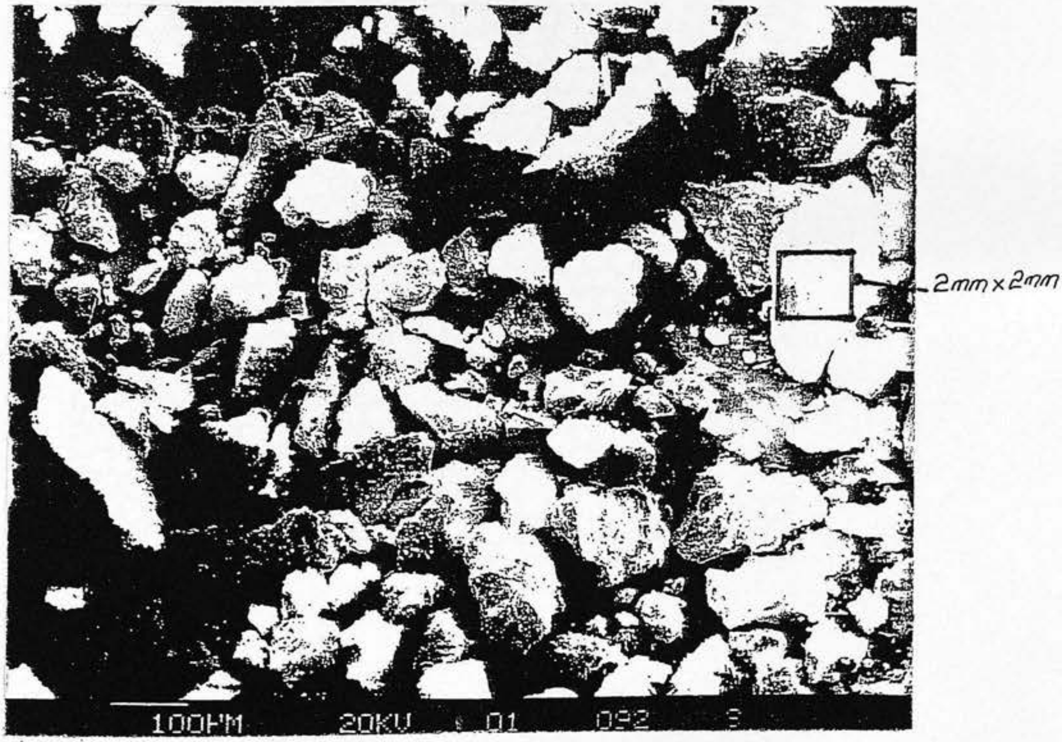



**Fig. 24 Grid scale development for the microstructure drawing**




Fine casting plaster




Fine grog

**Fig. 25 Creating a scale equivalence between the micrograph and the grid**

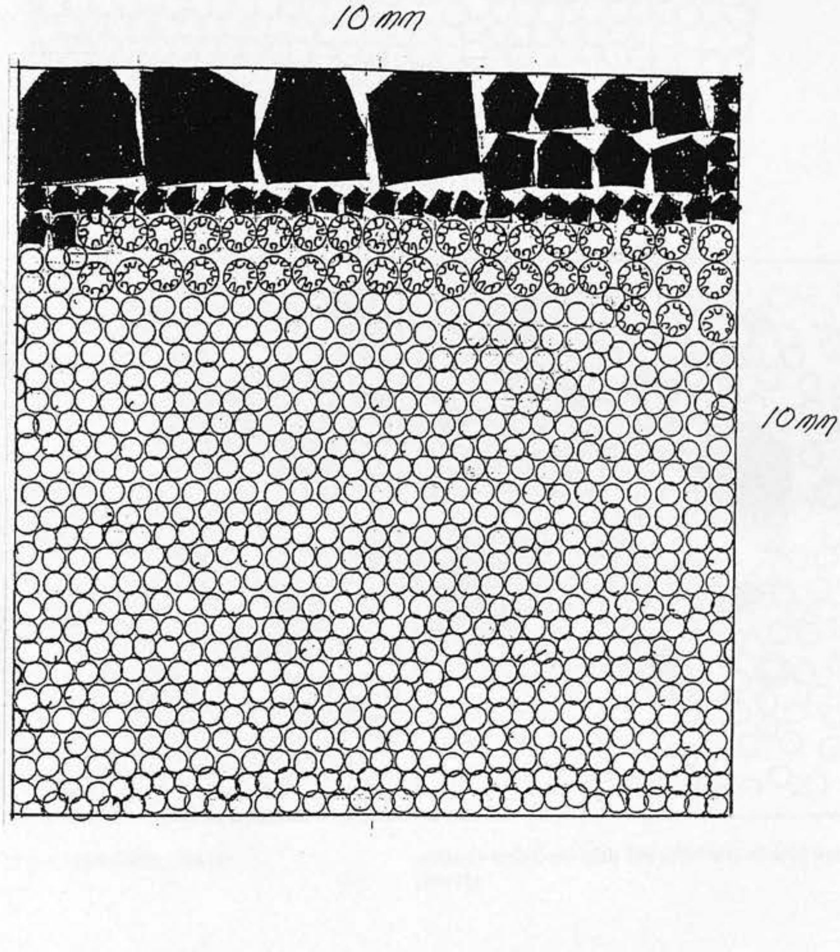
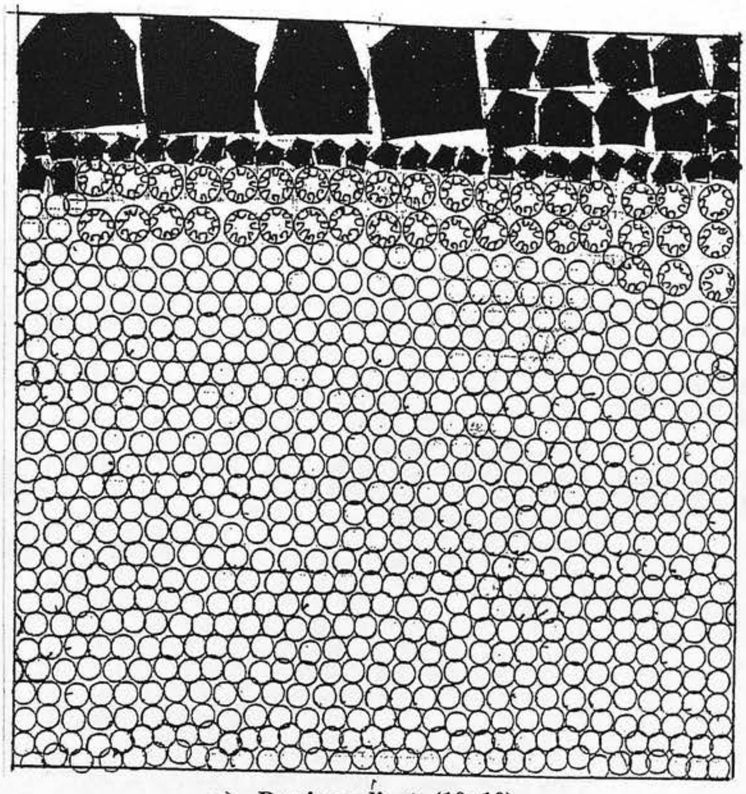
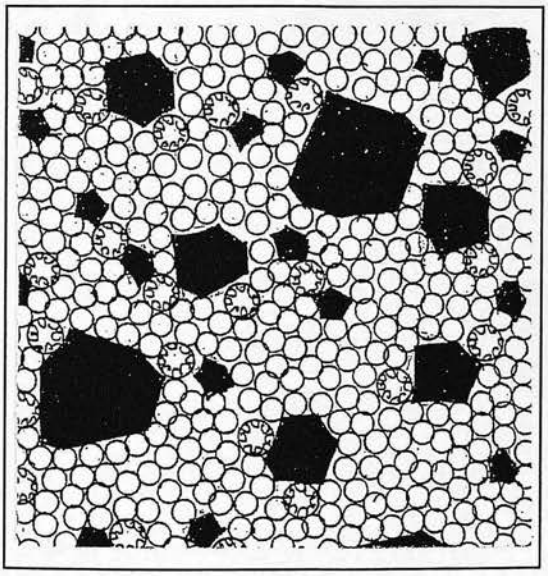


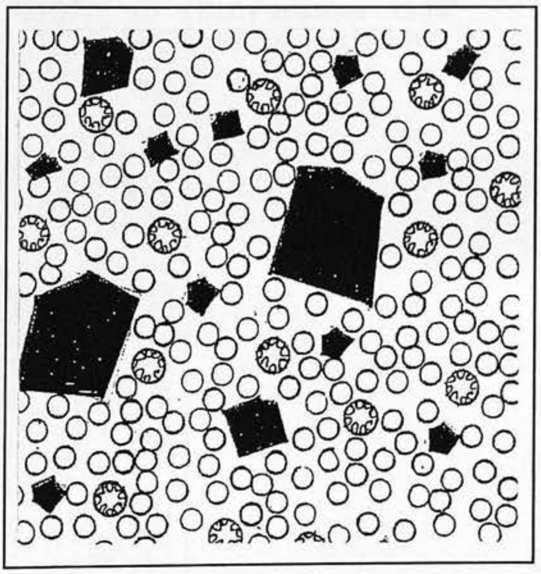

**Fig. 26 Proportioning the mixture for bronze mould 12**



a) Dry ingredients (10×10)



b) Distribution of dry ingredients (10×10)



c)Slurry technique with 400 millilitres of cold water `
(10×10)

**Fig. 27 Three stages in the development of the microstructure drawing for bronze mould 12**

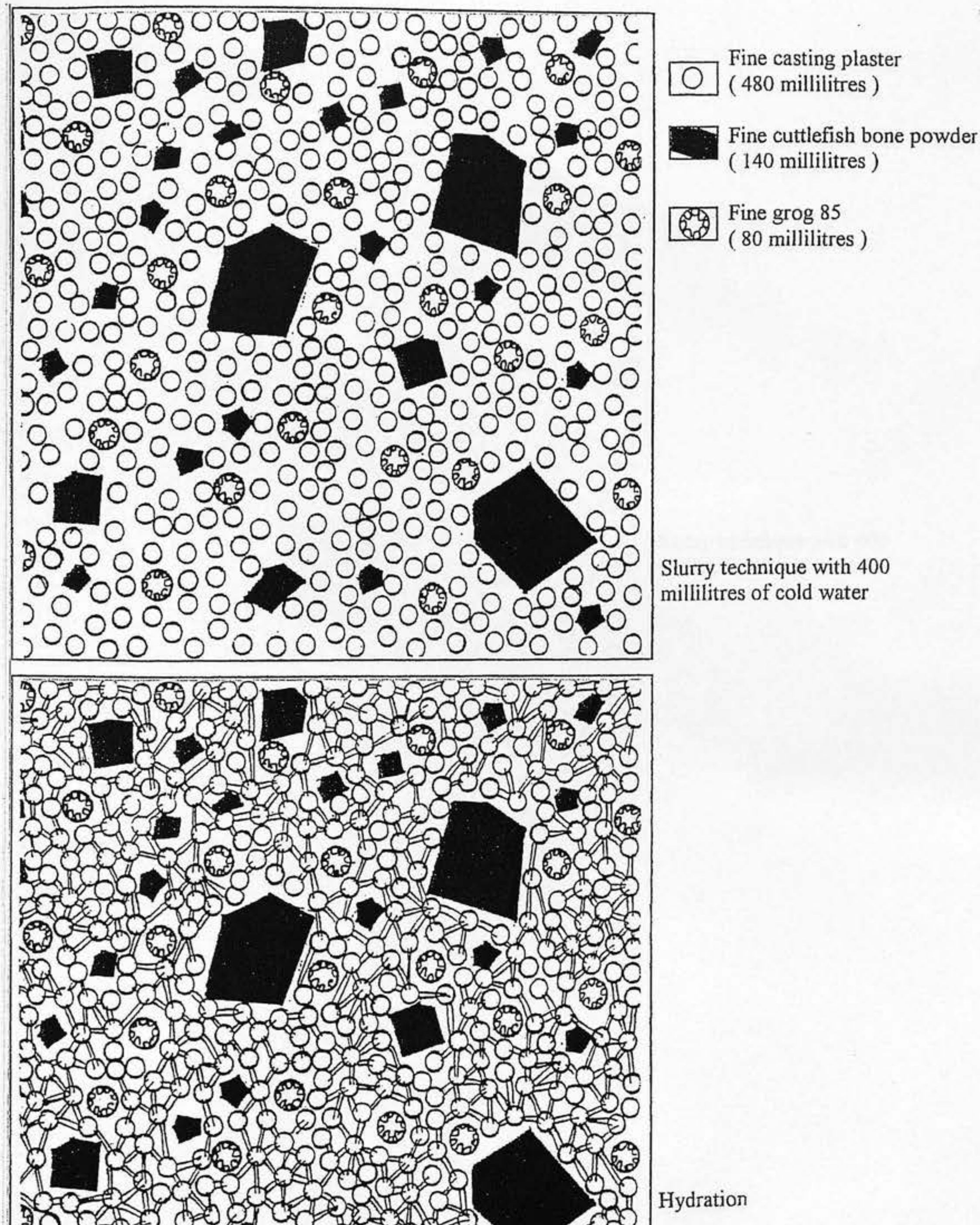



**Fig. 28 Microstructure drawings for bronze mould 12**

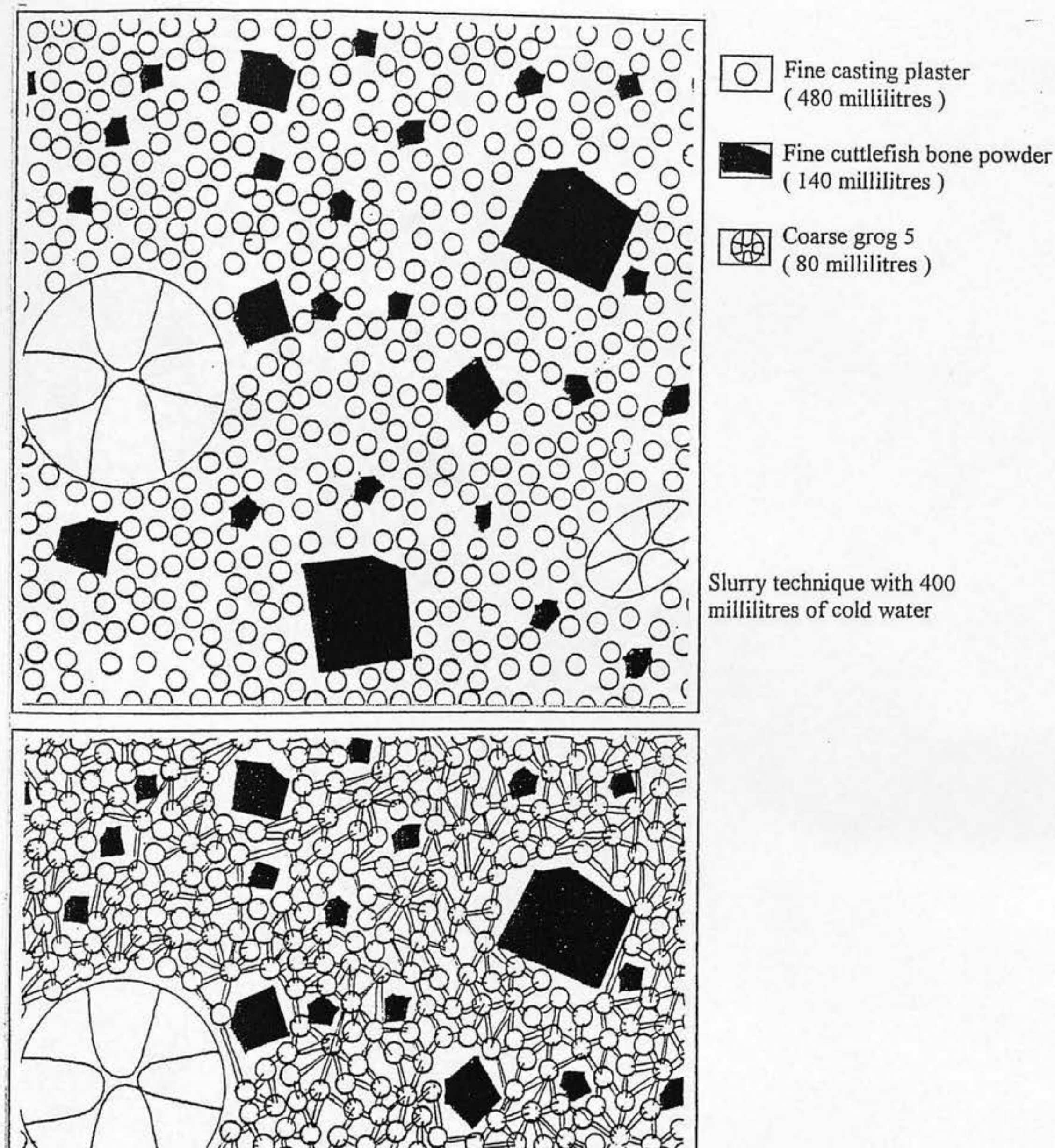



**Fig. 29 Microstructure drawings for bronze mould 13**

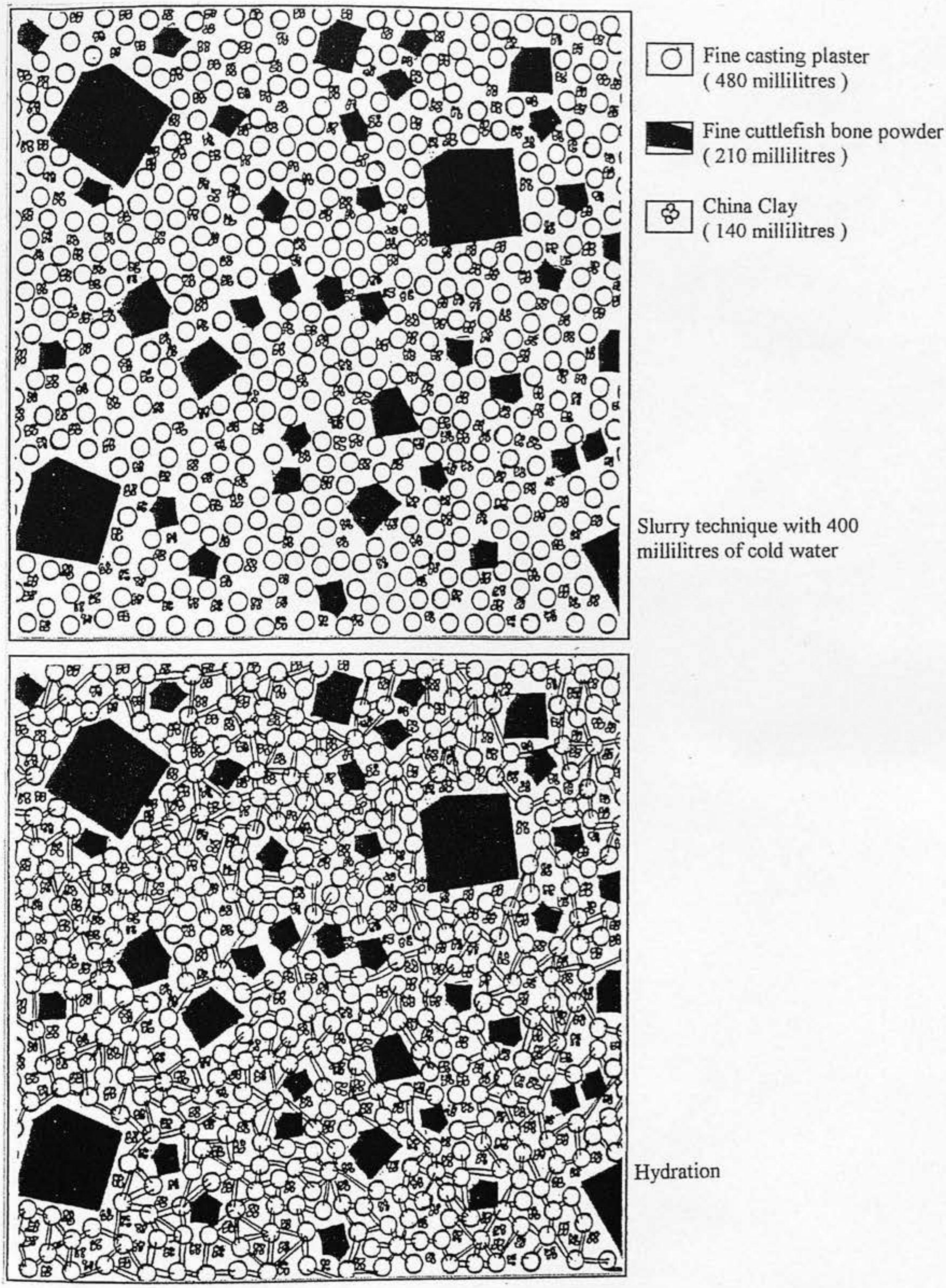



**Fig. 30 Microstructure drawings for bronze mould 17**

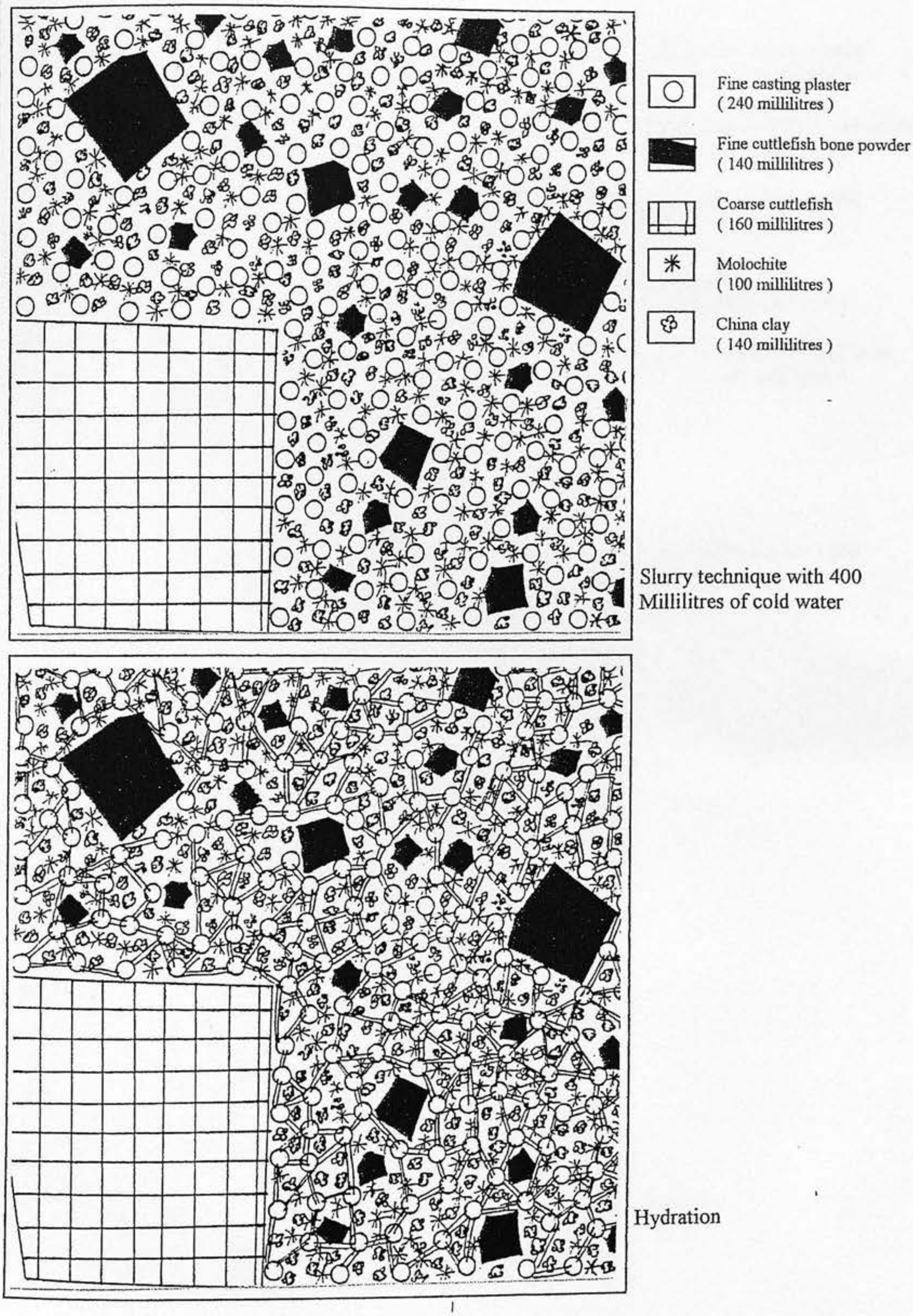



**Fig. 31 Microstructure drawings for bronze mould 24**

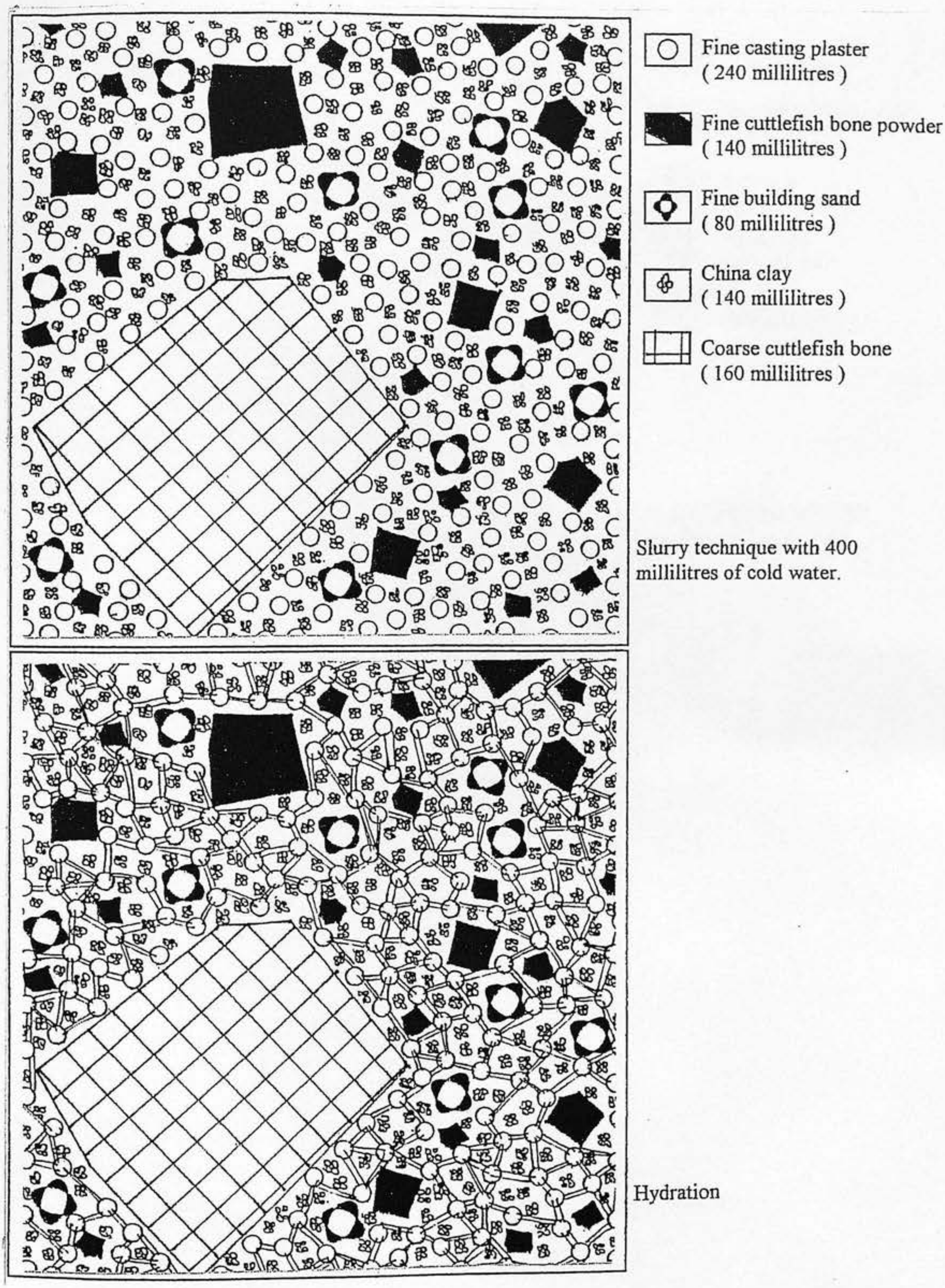



**Fig. 32 Microstructure drawings for bronze mould 25**

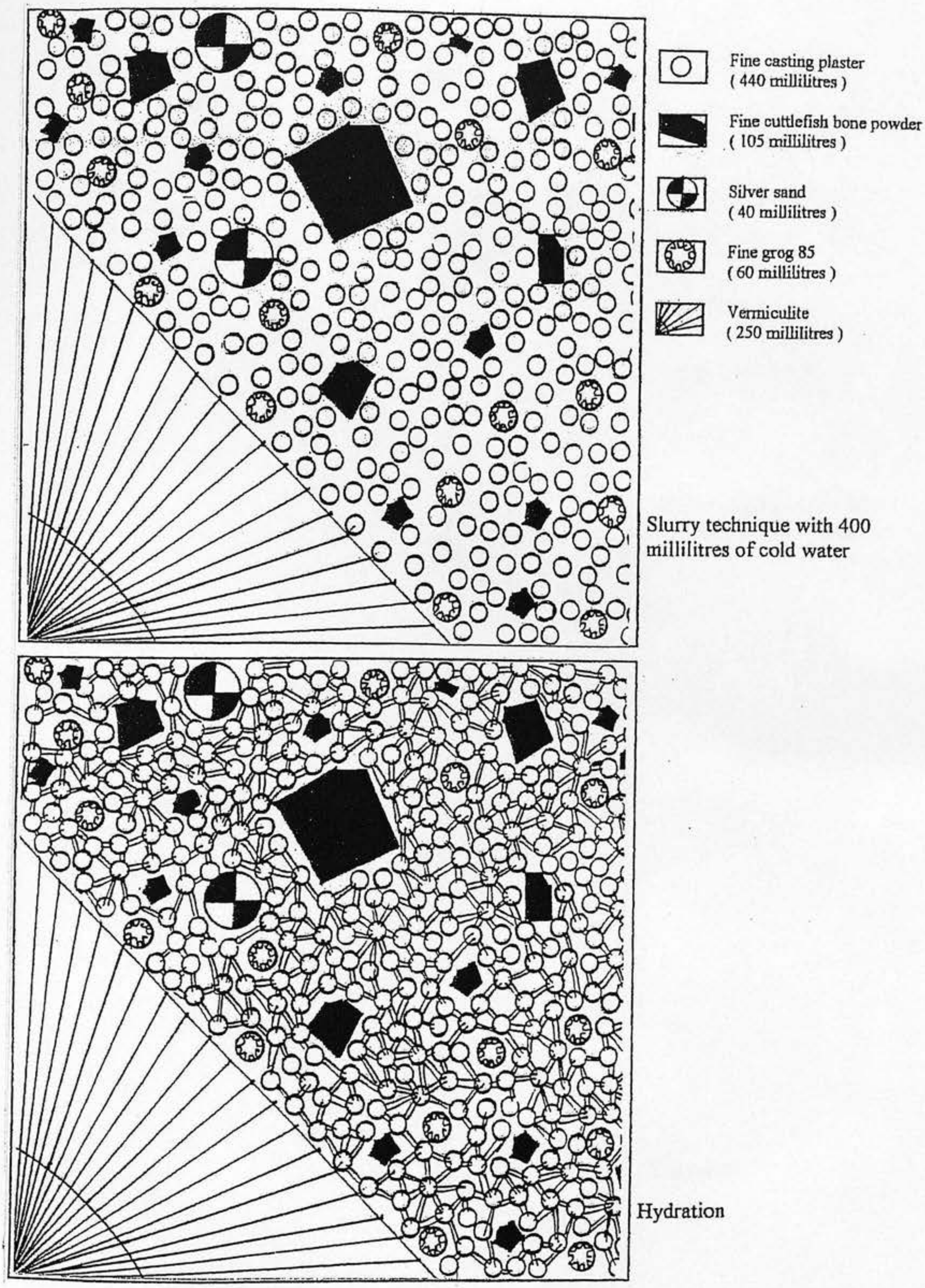



**Fig. 33 Microstructure drawings for glass mould 1**

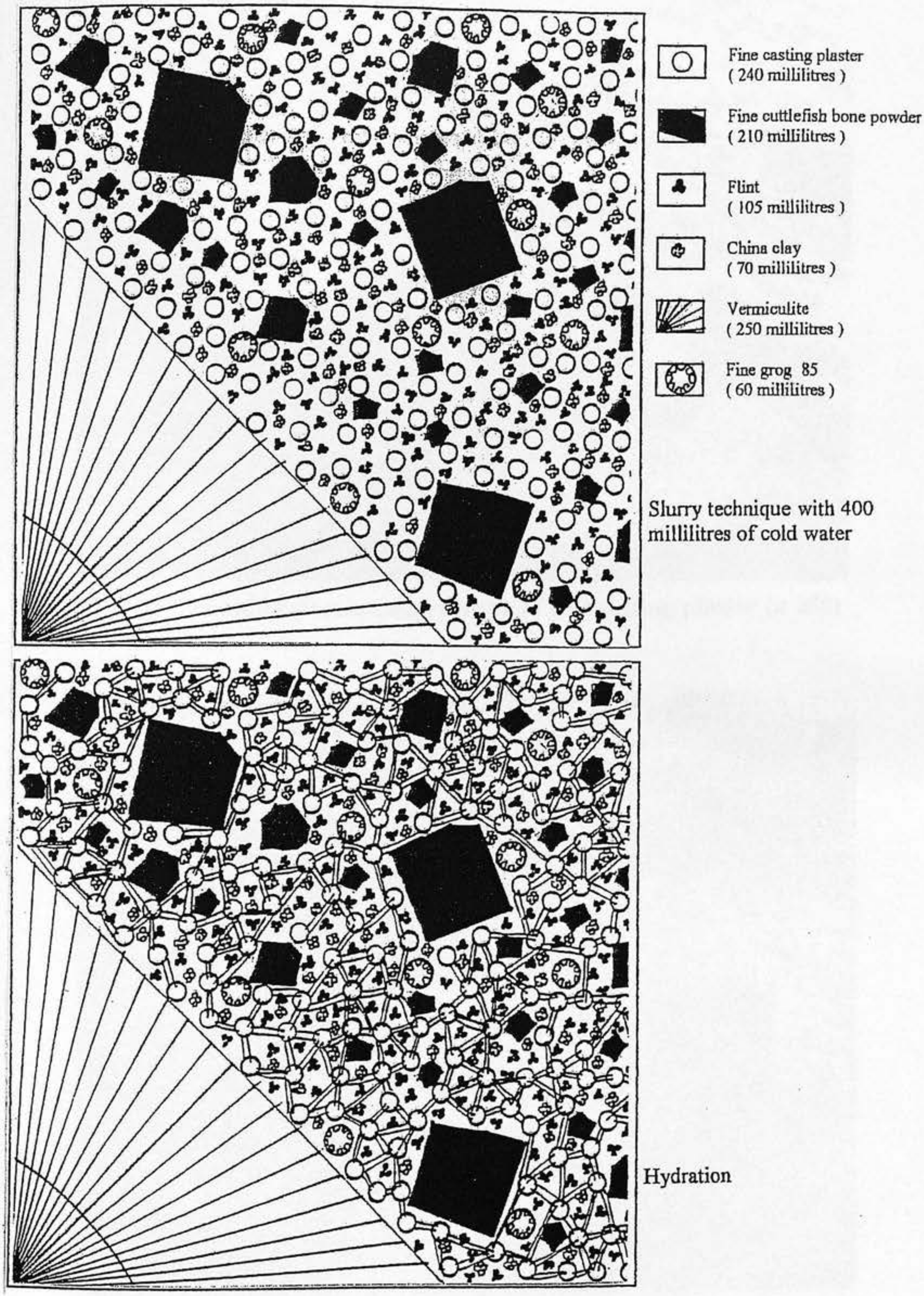



**Fig. 34 Microstructure drawings for glass mould 6**

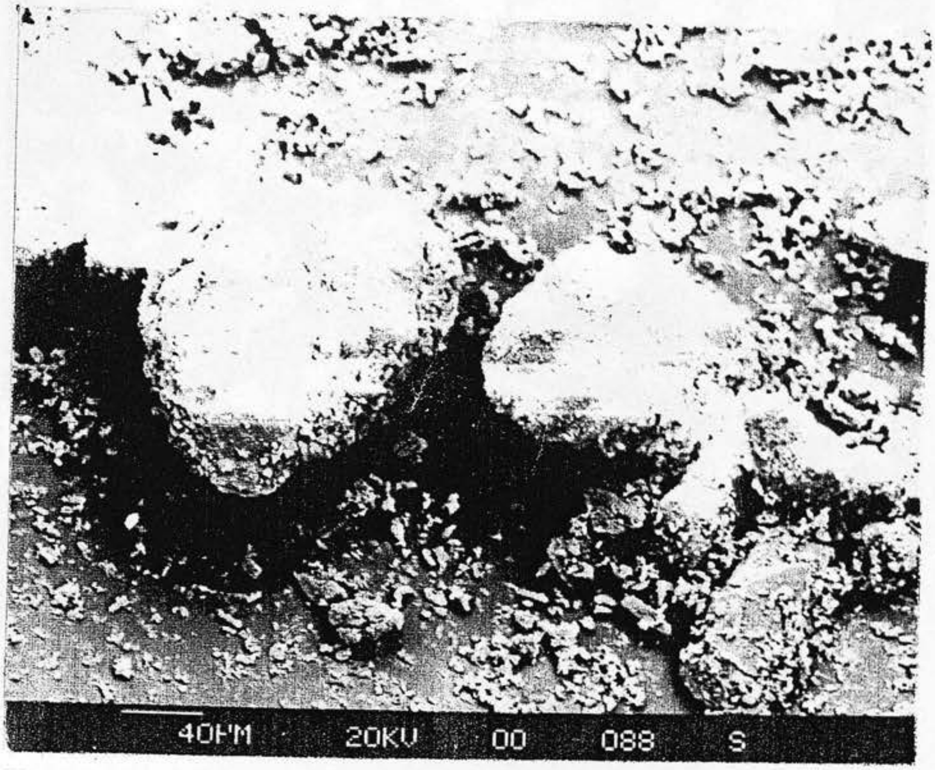



**Plate 17 Scanning electron micrograph of fine casting plaster (× 250)**

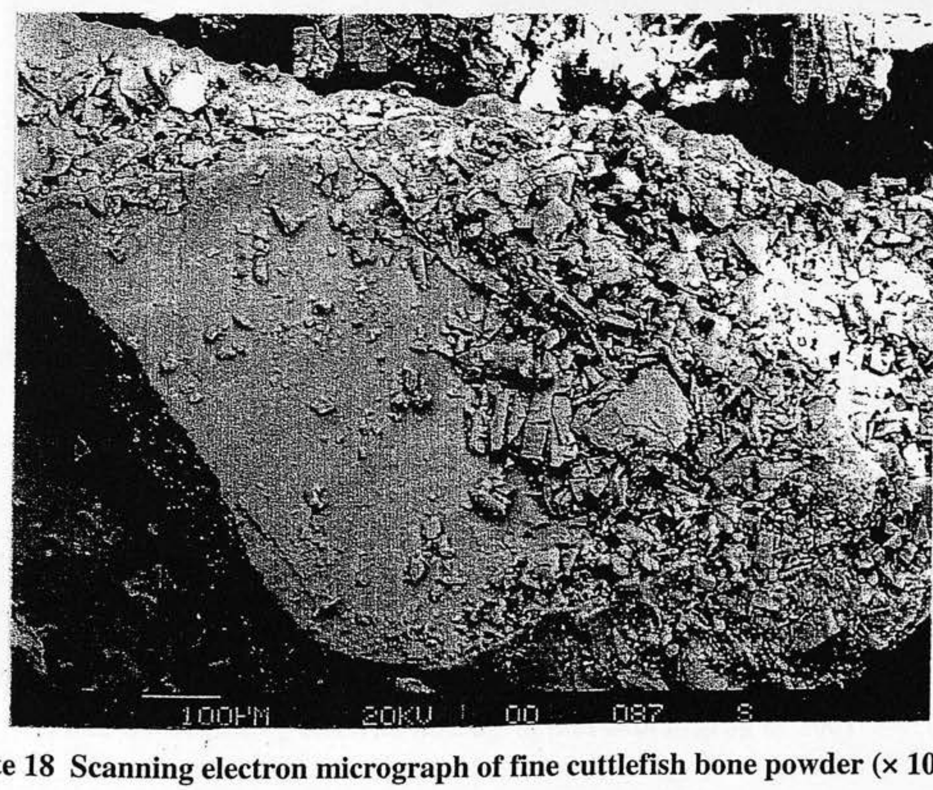



**Plate 18 Scanning electron micrograph of fine cuttlefish bone powder (× 100)**

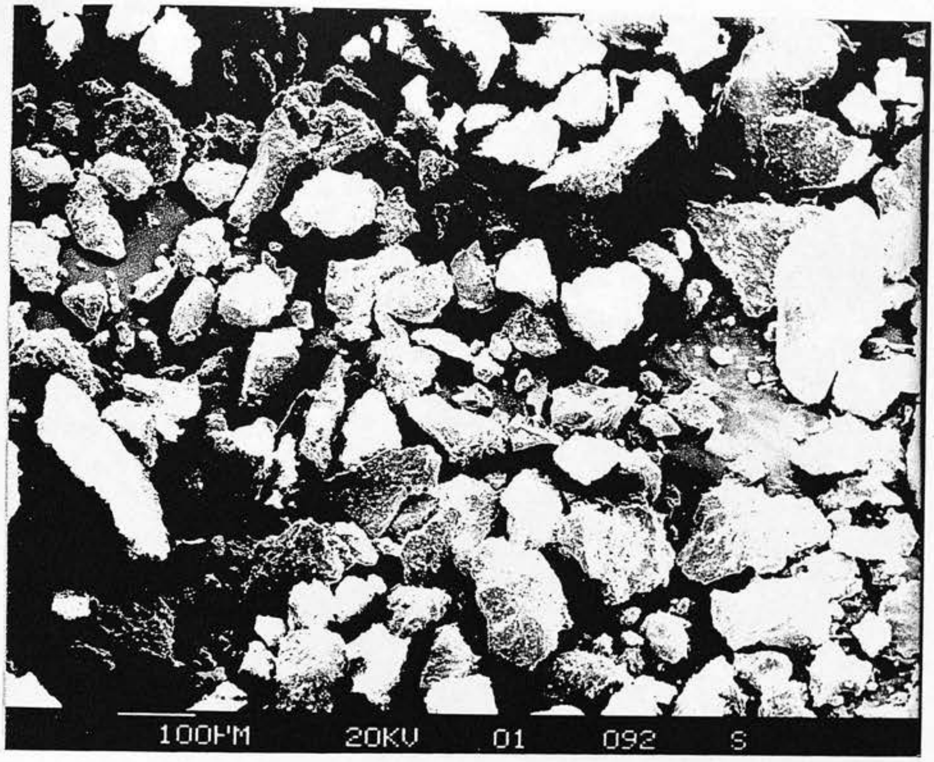



Plate 19 Scanning electron micrograph of fine grog (× 100)

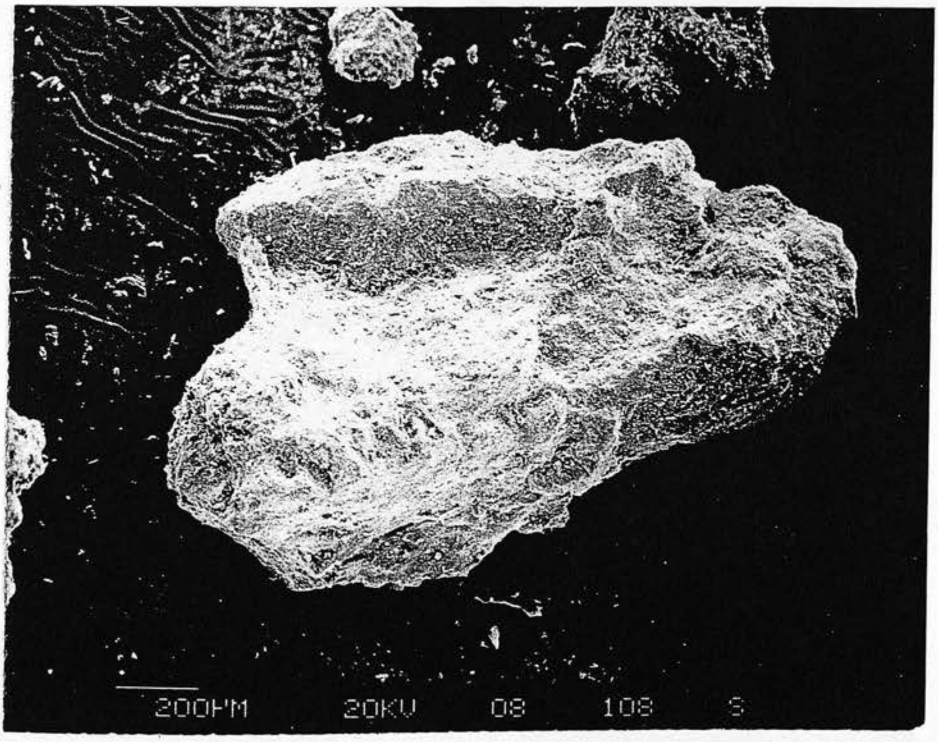



Plate 20 Scanning electron micrograph of coarse grog (× 100)

**Plate 21 Scanning electron micrograph of China clay (× 1000)**

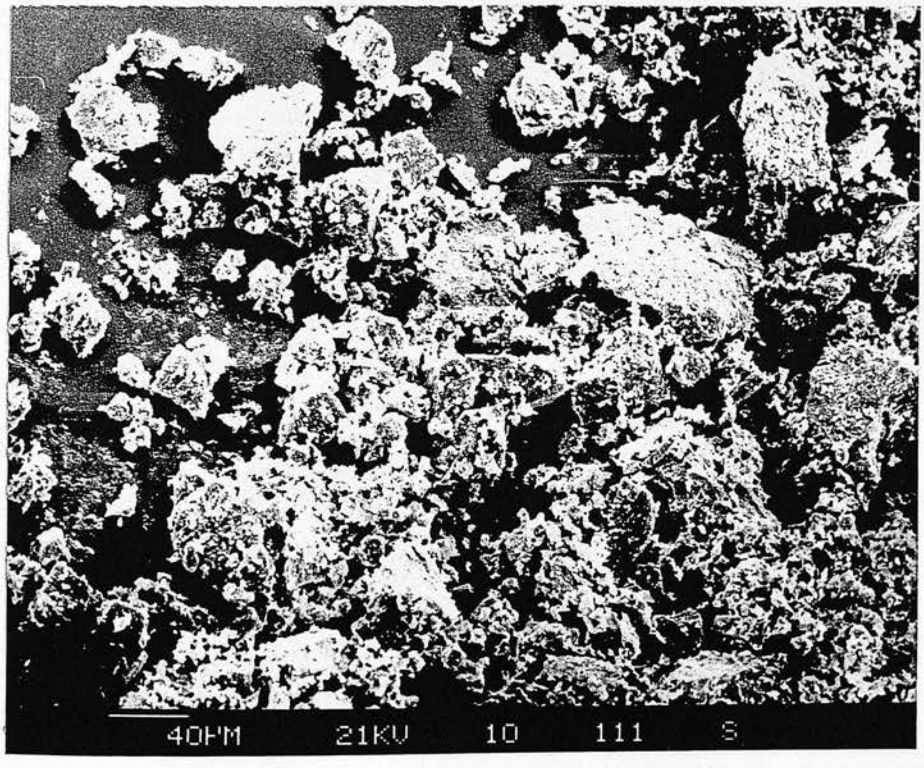


**Plate 22 Scanning electron micrograph of molochite (× 250)**

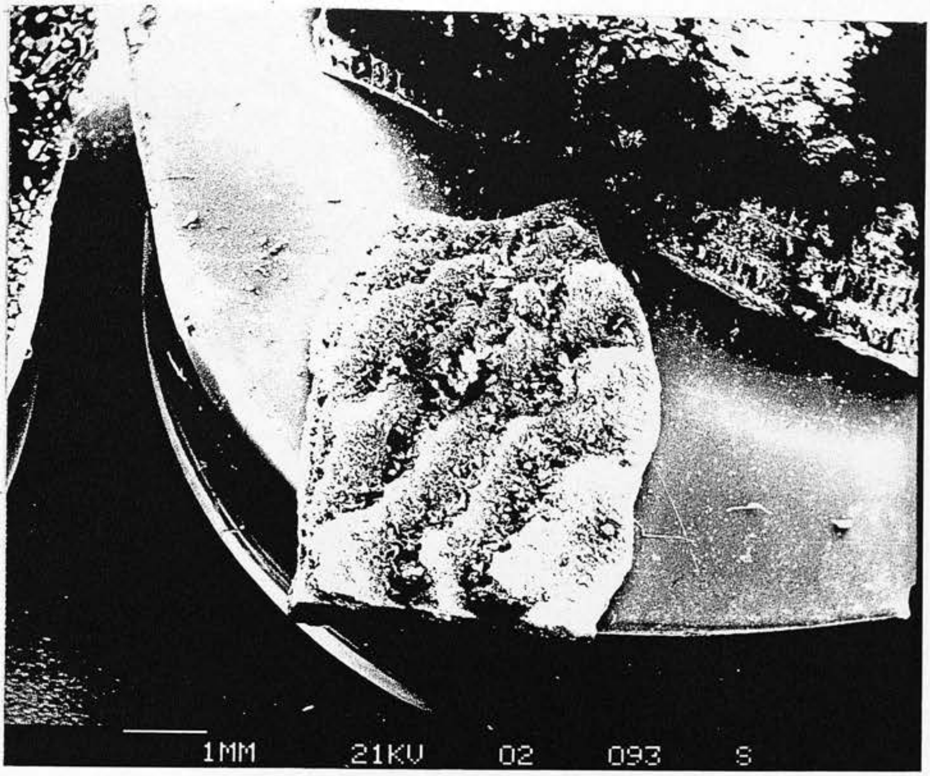



**Plate 23 Scanning electron micrograph of coarse cuttlefish bone (× 10)**

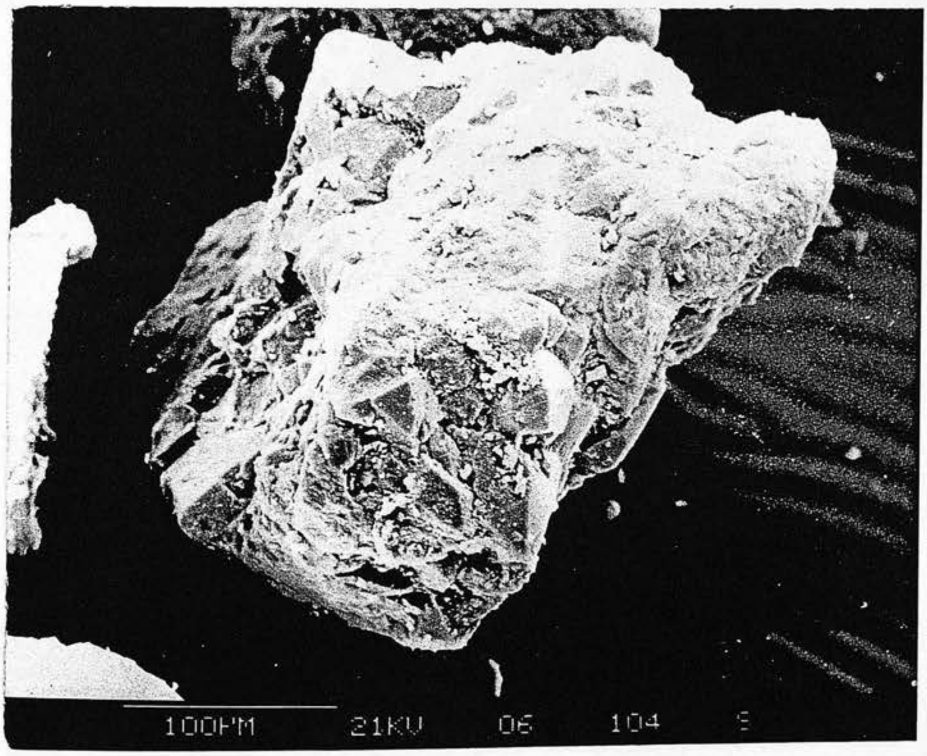



**Plate 24 Scanning electron micrograph of fine building sand (× 200)**

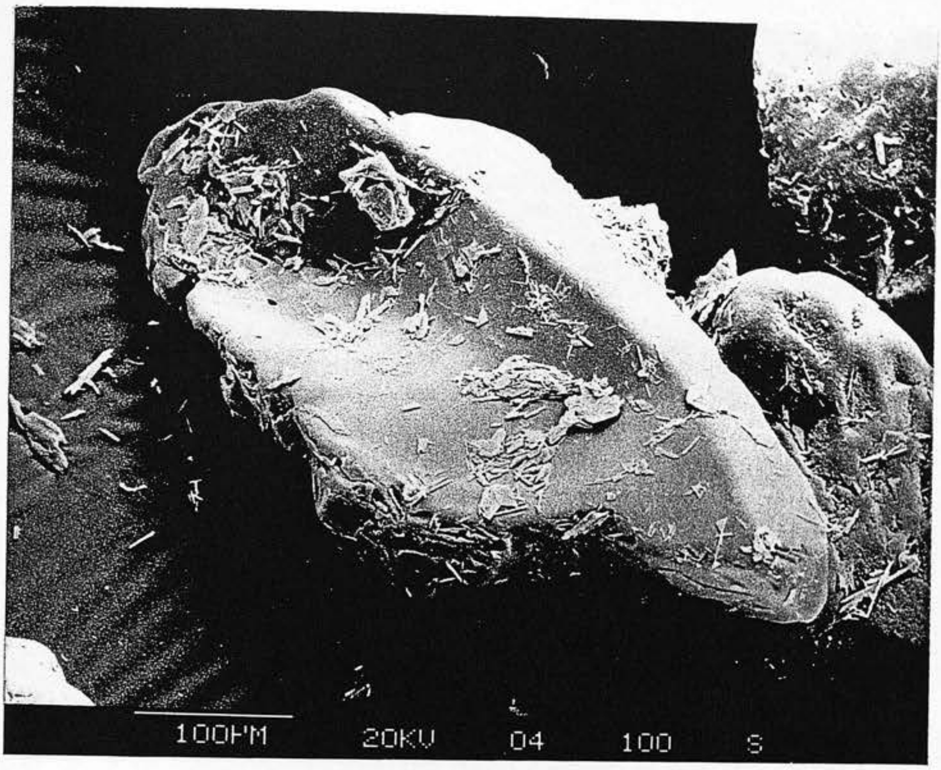



Plate 25 Scanning electron micrograph of silver sand (× 200)

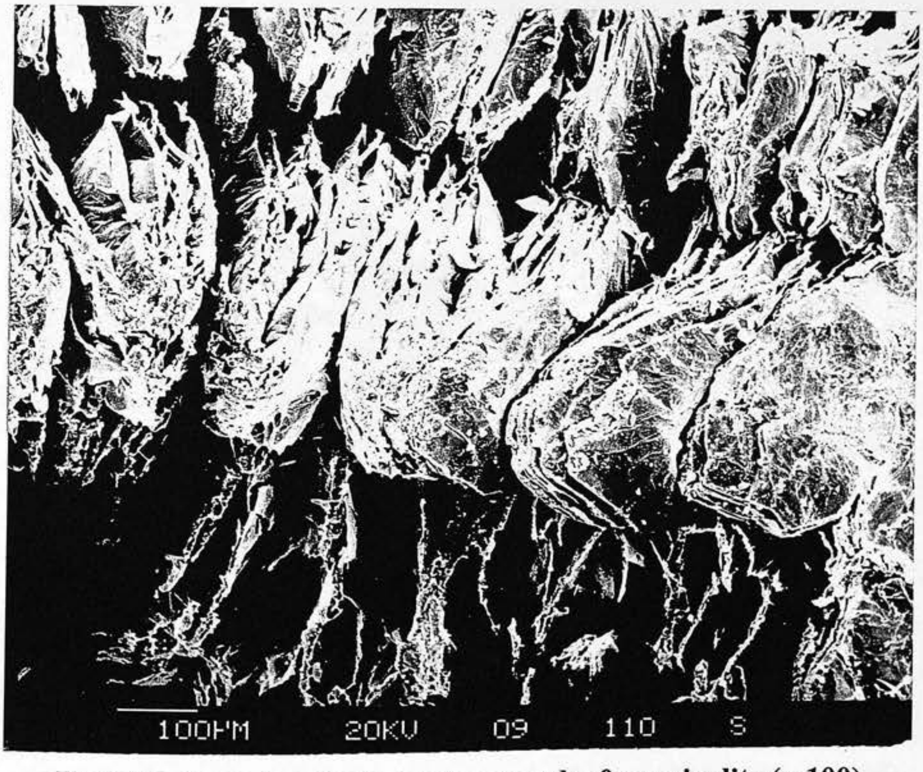



Plate 26 Scanning electron micrograph of vermiculite (× 100)

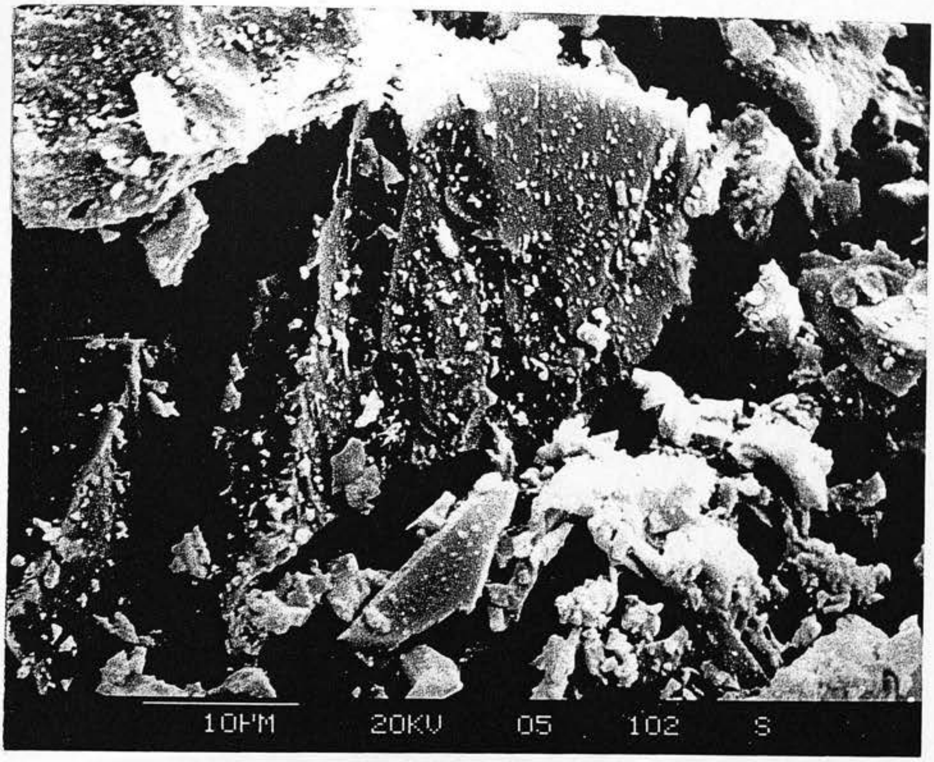



**Plate 27 Scanning electron micrograph of flint (× 2000)**

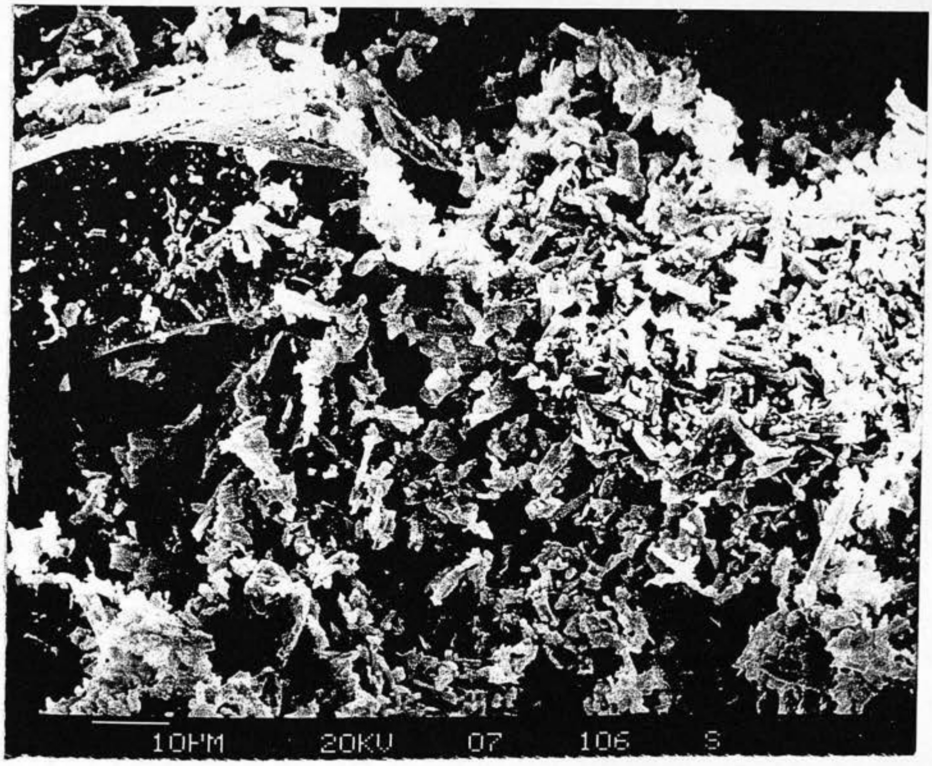



**Plate 28 Scanning electron micrograph of glass old mould (× 1000)**

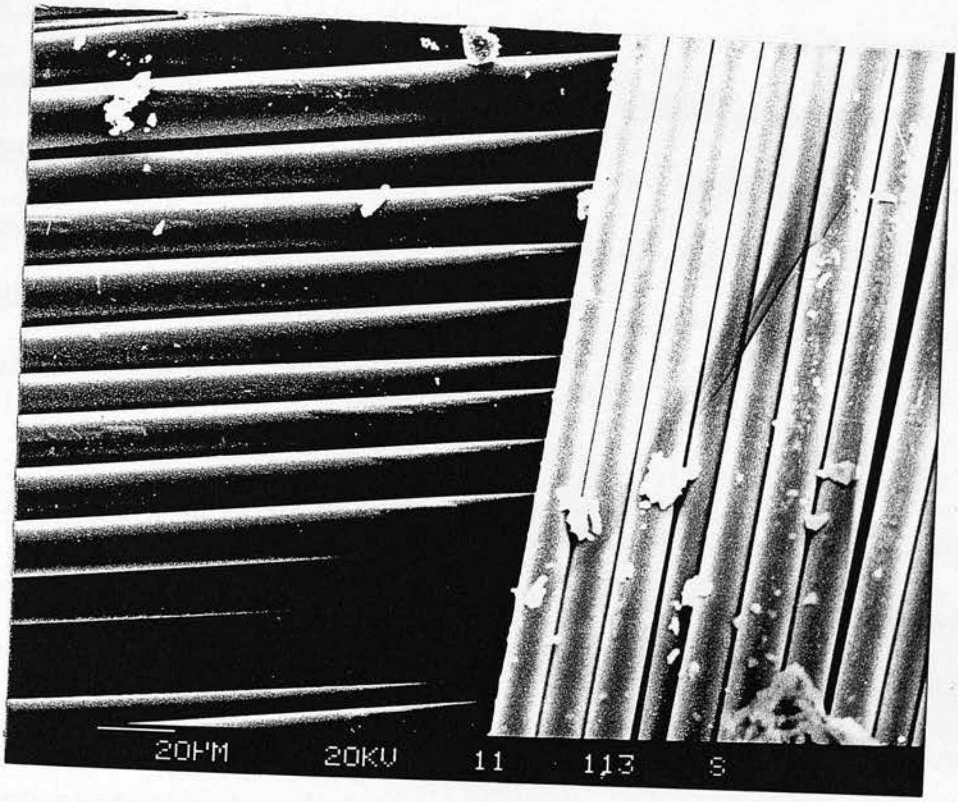



**Plate 29 Scanning electron micrograph of glass fibre (× 500)**

# Chapter 7. APPLICATION OF DRAWING TECHNIQUE TO EXPERIMENTAL RESULTS

In Chapter 6 a method was developed for expressing the formulations in a diagrammatic form which express the essential properties of the slurry and the hardened mould. In this chapter, the drawings are used to aid interpretation of the experimental results. Only the first set of these drawings (Fig. 35) has been prepared quantitatively using the technique described in Chapter 6; the remainder have been estimated based on the experience of a number of other calculated drawings.

The discussion is divided between bronze and glass moulds and between slurry behaviour and mould behaviour, reflecting the results of the experiments reported in Chapter 4 and 5. The approach is not exhaustive, being rather applied to a few key comparisons of behaviour of contrasting formulations so that the relationship between formulation and properties can be understood.

Figures 14 to 17, provided as fold-outs in Chapter 4, will be useful to illustrate this chapter.

## 7.1 Behaviour of bronze mould slurries

Formulations 7 and 8 provide a comparison of the relative roles of cuttlefish bone power and plaster on the behaviour of slurries containing approximately the same amount of water. Fig. 35 summarises the make-up, the structure and performance of the two formulations in a diagrammatic form. Comparison of the dry mixtures shows formulation 7 to have a higher proportion of the larger, more angular particles and one can imagine the handling characteristics being better for the one with higher plaster content. For the given amount of water one might expect the setting performance to be superior with formulation 8, as illustrated in the drawings of the hydrated structures.

The effect of water to "cement" ratio is illustrated in Fig. 36. Here, the ratio of plaster to cuttlefish powder is approximately the same, the contrast being the separation of the plaster particles in the slurry. This makes a thin mixture, and the slurry is unlikely to set properly because the density of hydrate "bridges" is low.

Formulations 12 and 13 introduce a new (refractory) component to the mixture, and a comparison of these with formulation 8 (Fig. 37) provides an indication of the effect of replacing some plaster and some cuttlefish bone powder with another refractory material (in this case either coarse or fine grog). Clearly, all other things being equal, acceptable handling and setting can be achieved by substituting a standard refractory, in equal proportions for cuttlefish bone powder and plaster. It appears to make little difference whether the grog is coarse or fine.

The left-hand panel of Fig. 38 illustrates the effect of china clay on handling and setting behaviour (contrast formulations 8 and 17). China clay is one of the finest ingredients used and its presence appears to allow the amount of plaster required to achieve setting to be reduced substantially. This, added to the effect of introducing further refractories (formulation 22) permits acceptable slurry behaviour with as little as 15% plaster.

### 7.2 Behaviour of hardened bronze moulds

The right-hand panel of Fig. 38 contrasts the heat resistance of the three formulations mentioned immediately above. Whereas all three formulations show acceptable handling and setting behaviour, two of the these formulations Bm 8 and Bm 17 are not successful at the firing and pouring stage, where the moulds crack and break leading to flash on the surface of the sculpture (Plate 30). The replacement of plaster with China clay in formulation 22 appears to have a strong positive influence on heat resistance.

The four formulations Bm 22, Bm 24, (Plates 31 and 32) Bm 31 and Bm 32 highlight the necessity of having a limited amount of plaster for good performance during pouring of bronze moulds. All four formulations (Fig. 39) survive firing, as might be expected from their China clay content, but only two (those with the lowest plaster contents) survive the higher temperatures and stresses of pouring. This may have something to do with the limited strength of the material, or even may be due to the plaster becoming desiccated, and losing its structural integrity.

## 7.3 Behaviour of glass mould slurry

The success rate of the glass slurry formulations was higher than that for bronze, probably because the glass slurry experiments followed from the bronze slurry research. Mixes for slurry were therefore informed by this experience.

However, the glass formulations tend to be more complex, probably because the required bulk is much higher and it is necessary to use as much filler material as possible. This also means that there ought to be greater potential for using cuttlefish bone powder in glass, or other unsupported, moulds.

Fig. 40 shows some of the wide range of formulations which exhibit acceptable setting behaviour, the only wholly unsatisfactory one illustrated being Gm7. This formulation has a very low plaster content, but lacks the complementary effect offered by the very fine China clay, and noted in the bronze moulds. The other (successfully setting) moulds which have a low plaster content were Gm4,5 and 6 each of which has some China clay in it.

## 7.4 Behaviour of hardened glass moulds

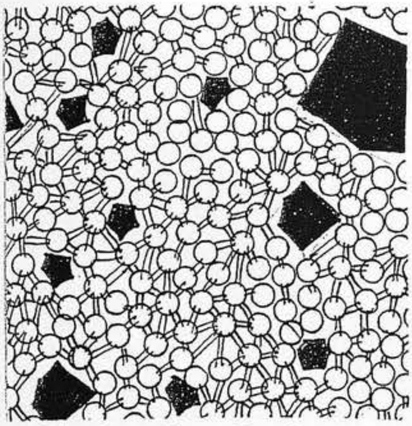
Glass moulds are not subjected to such high requirements in heat resistance terms nor do they have to cope with such sudden volume and weight pressures as in bronze casting. Consequently, a greater range of materials can be used successfully.

Fig. 41 illustrates some of this range, all of which contain vermiculite. The particle size of the vermiculite is so large that it tends to concentrate the remaining ingredients locally. This can be seen most clearly in Gm 29, where the plaster is so densely concentrated as almost to resemble Bm 8, and to be certainly denser than Bm 17 (Fig. 38). Such a high plaster density would probably not survive pouring in bronze, but is evidently adequate in glass, due to the bulk of the mould and the gentler temperatures and temperature gradients. The reason why this mould can be easily removed from the glass whereas one of a slightly lower plaster content (Gm 34, see table 11) cannot might be due to the presence of the large vermiculite particles in Gm 29.

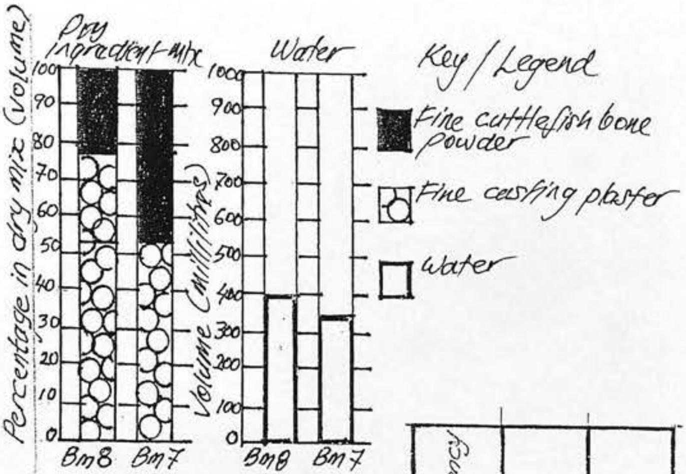
### 7.5 General discussion

This chapter has shown that a good deal of the behaviour of the formulations can be explained using microstructure drawing. However, the visualisation of the mould properties is considerably aided by a graphical presentation of the formulations (Figures 17-21). It is felt that microstructure drawing is good at highlighting relative sizes and shapes of ingredients and visualising complex mixtures. Its main weakness is in visualising relative quantities; it is, for example, easier to illustrate the difference between 20% and 25% plaster on a bar chart such as Fig. 17 than it is in a microstructure drawing.

It is therefore claimed that microstructure drawing is a useful adjunct to a visualisation of the formulation and helps to explain things that formulation alone cannot.



Hydration Bm 8

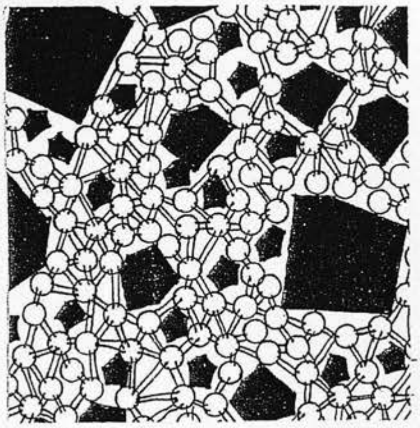



| Formulation | Total weight of the cuttlefish bone powder (kg) | Consistency | Setting time | Surplus water |
|---|---|---|---|---|
| Bm 8 | 0.125 | ✓ | ✓ | ✓ |
| Bm 7 | 0.25 | ✗ | ✗ | ✗ |

Slurry technique

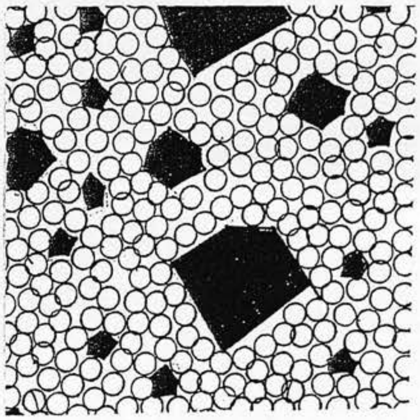
| Formulation | Slurry technique area | Slurry technique | Hydration |
|---|---|---|---|
| Bm 8 | 15.7x10cm | successful | successful |
| Bm 7 | 14.6x10cm | too thick | too close |

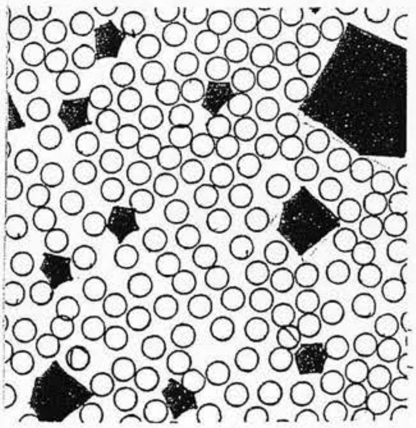
Test note



Hydration Bm 7

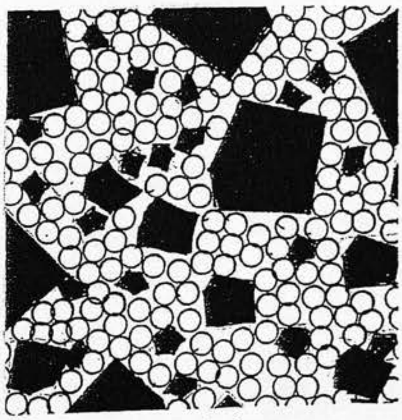
Dry ingredient Bm 8

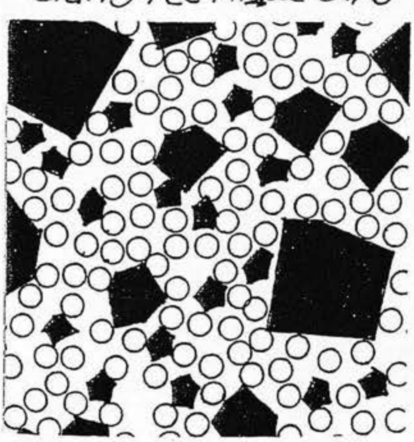




Slurry technique Bm 8

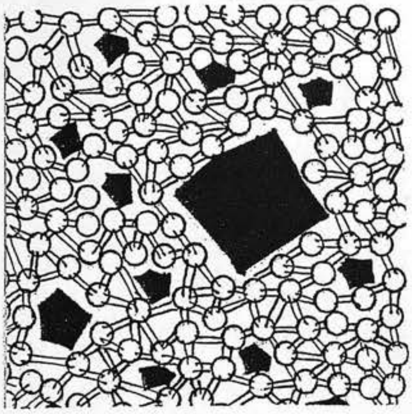
Dry ingredient Bm 7



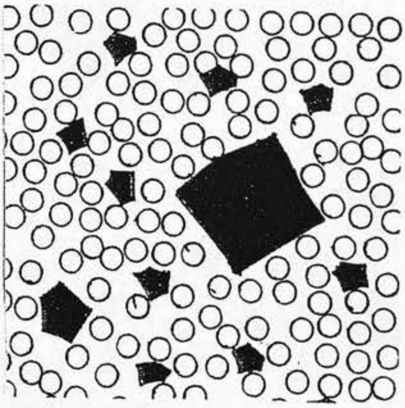


Slurry technique Bm 7

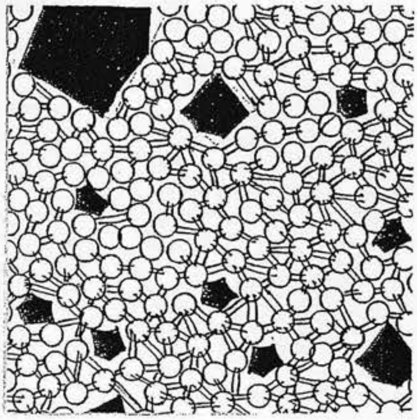
Fig. 35 Comparison of bronze moulds 7 and 8 showing the relative effect of cuttlefish bone powder and plaster



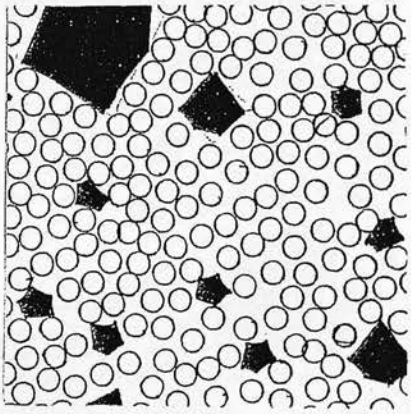
Hydration Bm 3



Slurry technique Bm 3



Hydration Bm 8

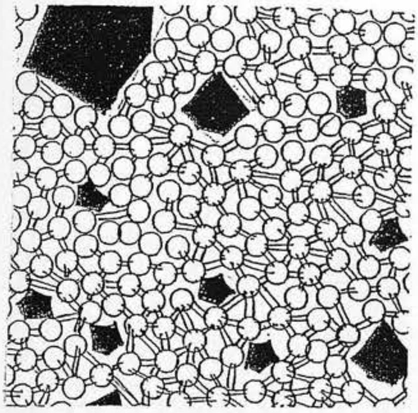


Slurry technique Bm 8

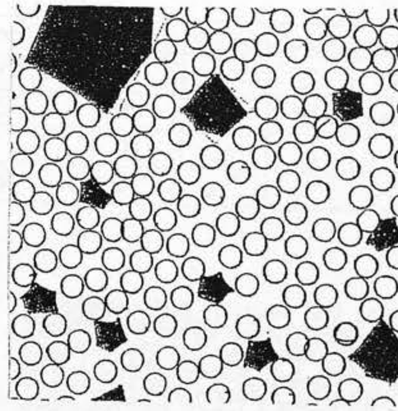
| Formulation | Total weight of the cuttle fish bone powder (Kg) | Consistency | Setting time | Surplus water |
|---|---|---|---|---|
| Bm 3 | 0.15 | × | × | × |
| Bm 8 | 0.125 | ✓ | ✓ | ✓ |

slurry technique

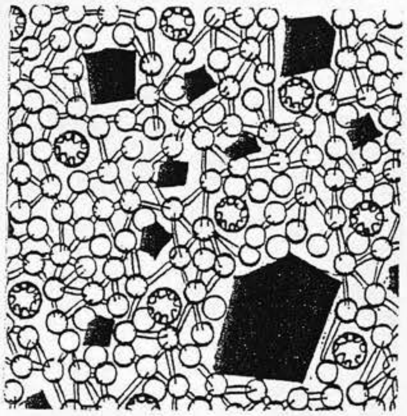
Fig. 36 Evaluation of water to cement ratio



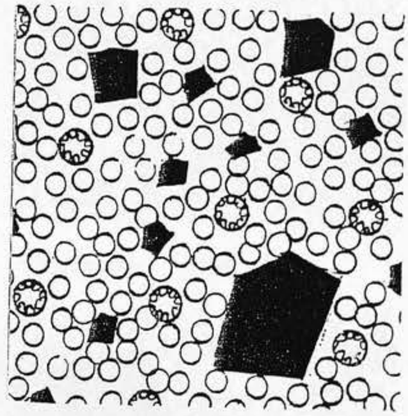
Hydration Bm 8



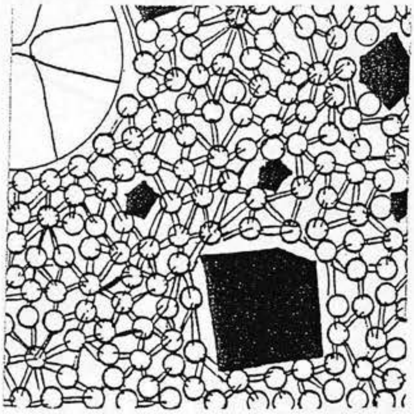
Slurry technique Bm 8



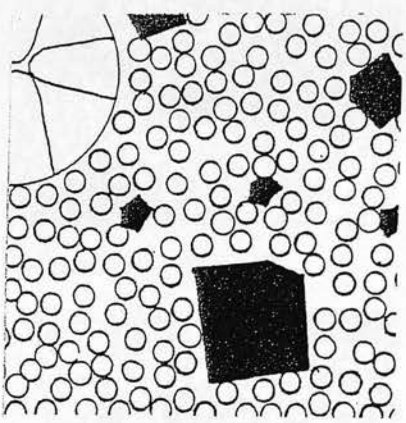
Hydration Bm 12



Slurry technique Bm 12



Hydration Bm 13

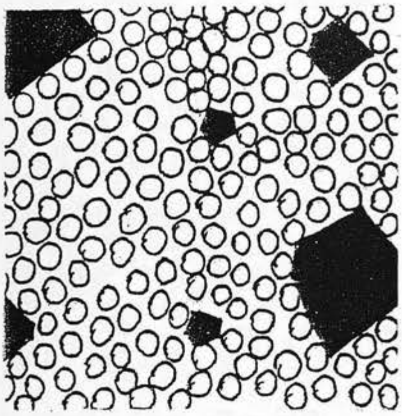


Slurry technique Bm 13

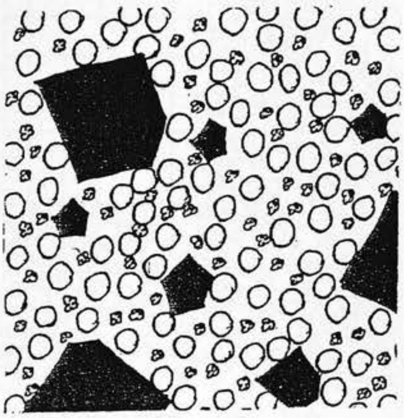
| Formulation | Total weight of the cuttlefish bone powder (kg) | Consistency | Setting time | Surplus water |
|---|---|---|---|---|
| Bm 8 | 0.125 | ✓ | ✓ | ✓ |
| Bm 12 | 0.1 | ✓ | ✓ | ✓ |
| Bm 13 | 0.1 | ✓ | ✓ | ✓ |

Slurry technique

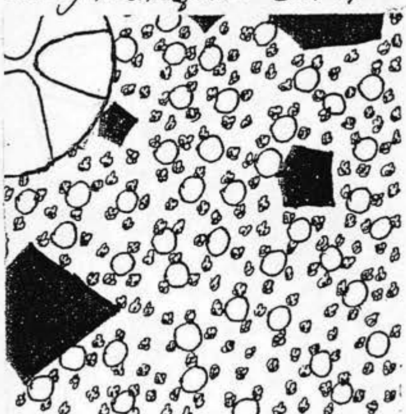
Fig. 37 The effect of additional refractory materials on slurry behaviour



Slurry technique Bm 8



Slurry technique Bm 17



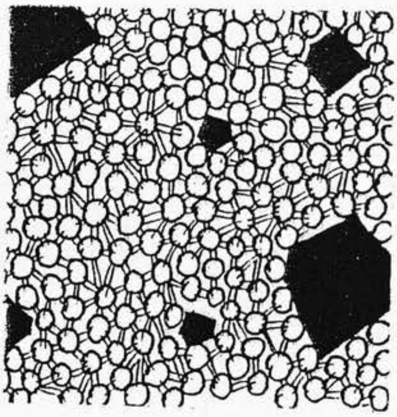
Slurry technique Bm 22

| Formulation | Total weight of the cuttlefish bone powder (kg) | Consistency | Setting time | Surplus water |
|---|---|---|---|---|
| Bm 8 | 0.125 | ✓ | ✓ | ✓ |
| Bm 17 | 0.15 | ✓ | ✓ | ✓ |
| Bm 22 | 0.125 | ✓ | ✓ | ✓ |

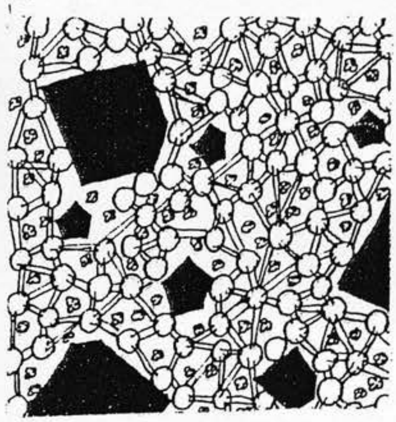
Slurry technique

| Formulation | Total weight of the cuttlefish bone powder (kg) | Criteria 1 | Criteria 2 | Criteria 3 | Criteria 4 |
|---|---|---|---|---|---|
| Bm 8 | 0.125 | × | × | × | ✓ |
| Bm 17 | 0.15 | × | × | × | ✓ |
| Bm 22 | 0.125 | ✓ | ✓ | ✓ | ✓ |

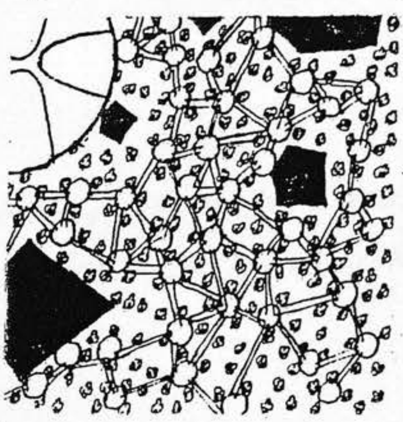
Heat resistance



Hydration Bm 8



Hydration Bm 17

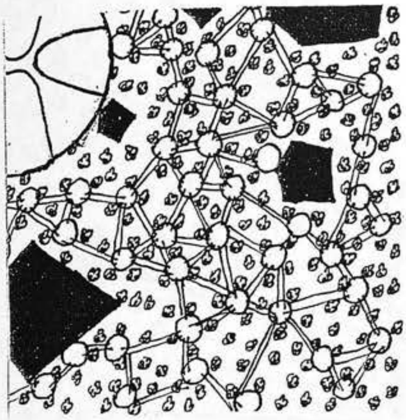


Hydration Bm 22

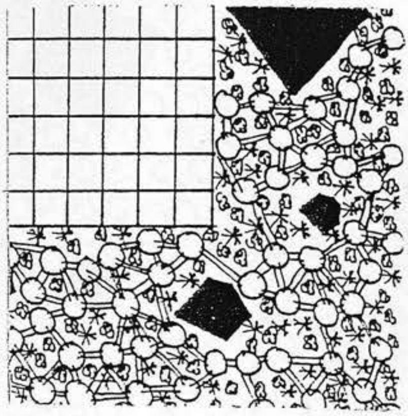
Fig. 38 The effect of China clay on slurry behaviour and resistance

| Formulation | Total weight of the cuttlefish bone powder (kg) | Criteria 1 | Criteria 2 | Criteria 3 | Criteria 4 |
|---|---|---|---|---|---|
| Bm 22 | 0.125 | ✓ | ✓ | ✓ | ✓ |
| Bm 24 | 0.2 | ✓ | ✓ | ✓ | ✓ |
| Bm 31 | 0.1 | ✓ | ✗ | ✗ | ✓ |
| Bm 32 | 0.1 | ✓ | ✗ | ✗ | ✓ |

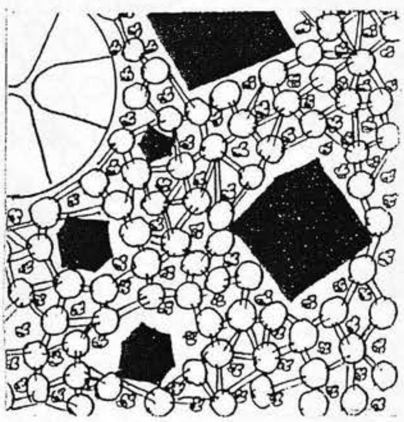
Heat resistance



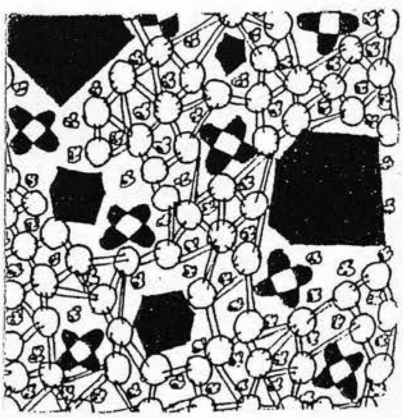
Hydration Bm 22



Hydration Bm 24

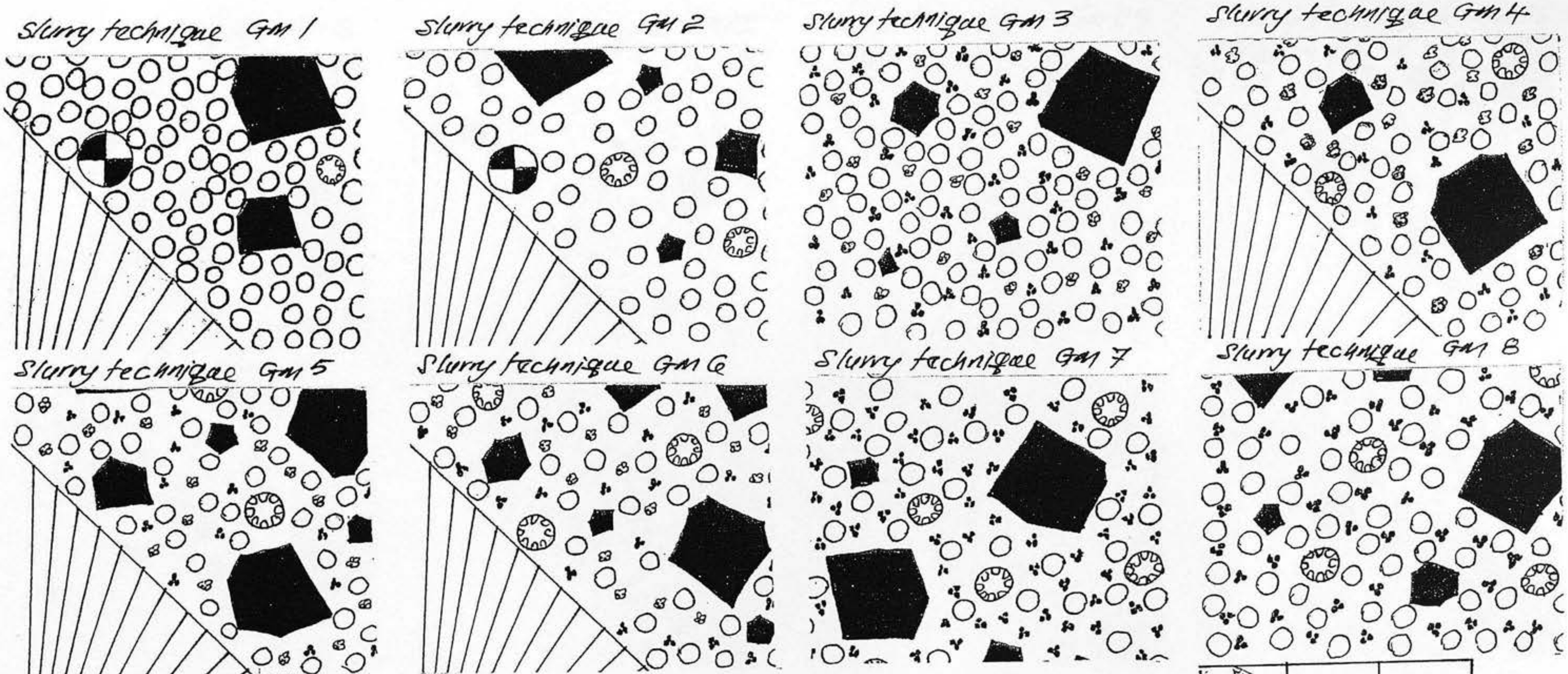


Hydration Bm 31



Hydration Bm 32

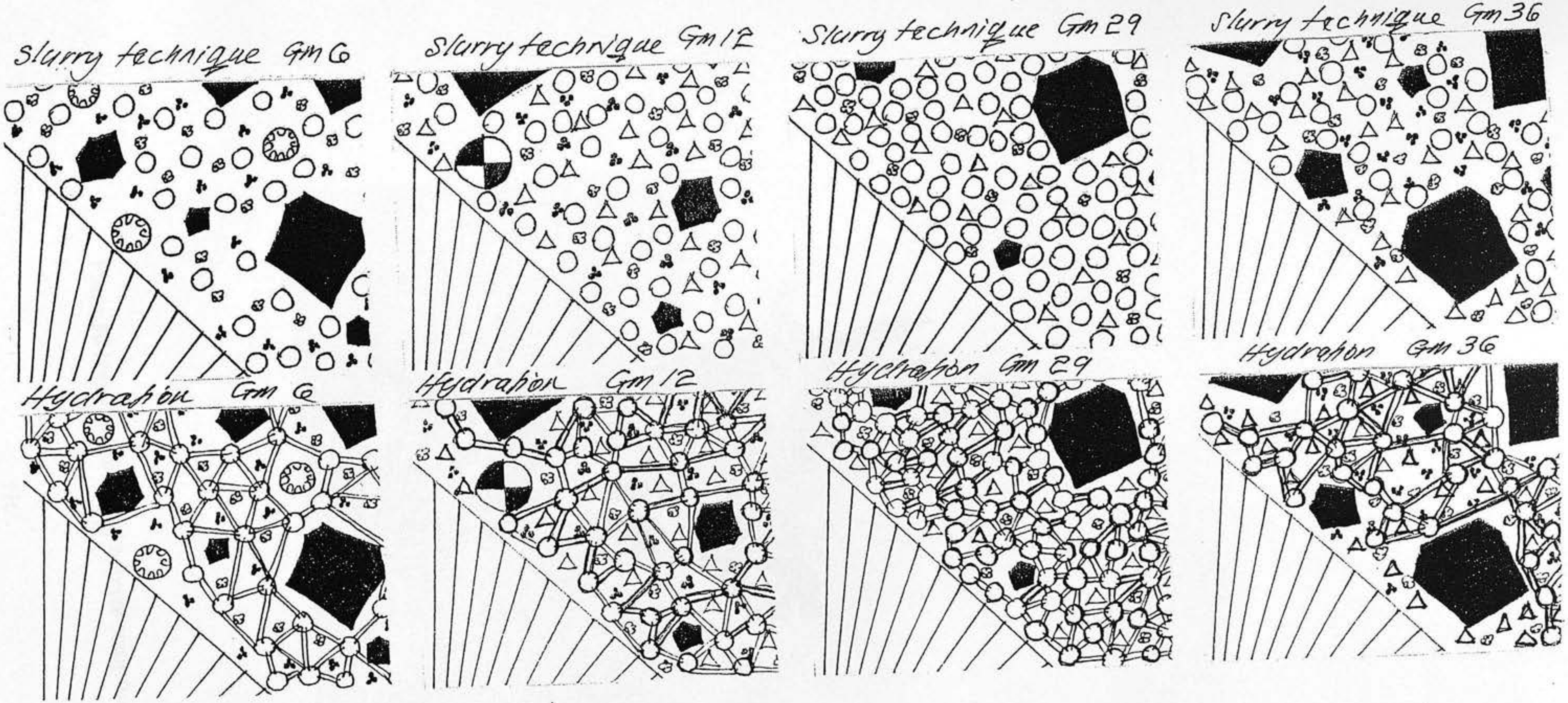
Fig. 39 Comparison of moulds showing acceptable performance during firing




Slurry technique

| Formulation | Total weight of the cuttlefish bone powder (kg) | Consistency | Setting time | Surplus water |
|---|---|---|---|---|
| Gm 1 | 0.075 | ✓ | ✓ | ✓ |
| Gm 2 | 0.1 | ✓ | ✓ | ✓ |
| Gm 3 | 0.1 | ✓ | ✓ | ✓ |
| Gm 4 | 0.075 | ✗ | ✓ | ✓ |
| Gm 5 | 0.15 | ✗ | ✓ | ✓ |
| Gm 6 | 0.15 | ✓ | ✓ | ✓ |
| Gm 7 | 0.125 | ✗ | ✗ | ✗ |
| Gm 8 | 0.1 | ✓ | ✓ | ✓ |

Fig. 40. Effect of size of material (aggregate), quantity of plaster to aggregate and amount of water, on glass mould setting behaviour




| Formulation | Total weight of the cuttlefish bone powder (kg) | no cracking | no feathers | easily removed |
|---|---|---|---|---|
| Gm 6 | 0.15 | ✓ | ✓ | ✓ |
| Gm 12 | 0.1 | ✓ | ✓ | ✓ |
| Gm 29 | 0.1 | ✓ | ✓ | ✓ |
| Gm 36 | 0.15 | ✓ | ✓ | ✓ |

Heat resistance

Slurry technique

| Formulation | Total weight of the cuttlefish bone powder (kg) | Consistency | Setting time | Surplus water |
|---|---|---|---|---|
| Gm 6 | 0.15 | ✓ | ✓ | ✓ |
| Gm 12 | 0.1 | ✓ | ✓ | ✓ |
| Gm 29 | 0.1 | ✓ | ✓ | ✓ |
| Gm 36 | 0.15 | ✓ | ✓ | ✓ |

Fig. 41 Range of successful glass moulds,
all containing vermiculite.

**Plate 30 Heavily feathered bronze sculpture**

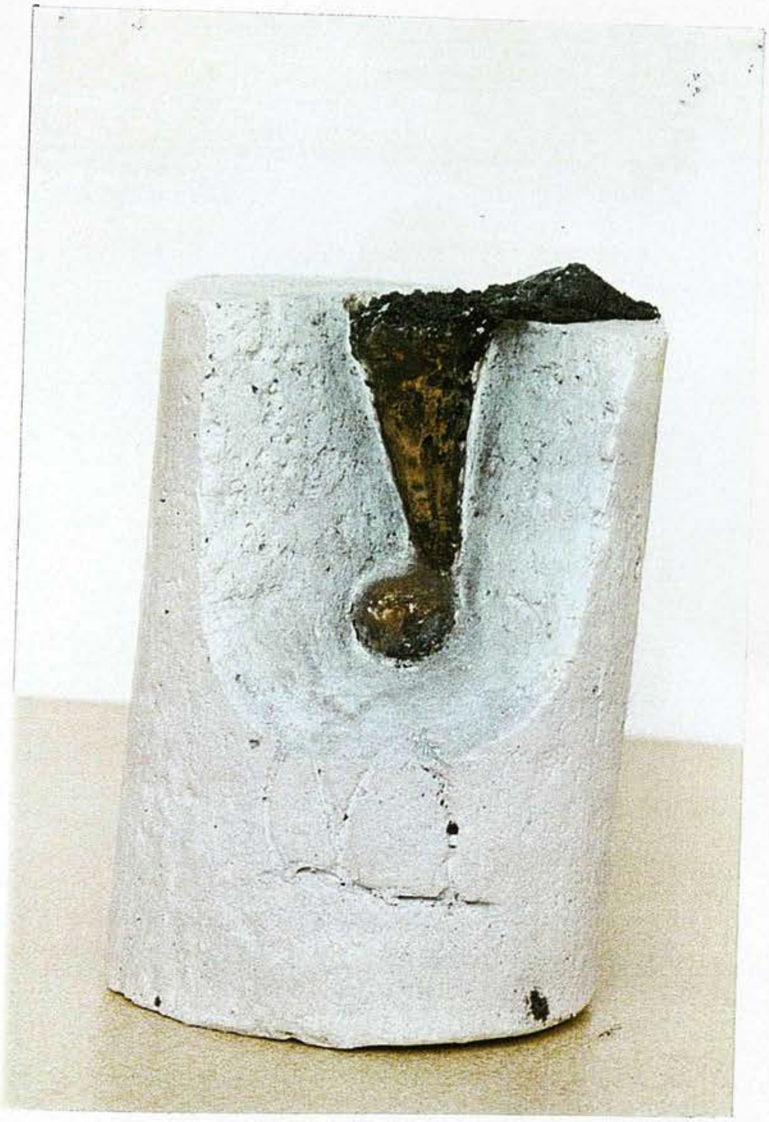


**Plate 31 Successful bronze investment casting mould**

**Plate 32 Successful bronze sculpture**

## Chapter 8. DISCUSSION OF METHODOLOGY

The work started as an investigation into the use of cuttlefish bone powder as a heat-resistant extender in bronze and glass investment casting moulds for fine art sculptures. To this end, a series of trial-and-error experiments was carried out aimed at finding a range of formulations which showed the right kind of handling and setting characteristics and which were resistant to the thermal and mechanical exposure of the firing and casting processes.

In the course of investigation, particularly in the literature review, it became evident that practitioners were using this same method of trial and error using the "feel" of a mixture to assess the handling and pouring of mould slurries, and that word of mouth was the most common means of communication used. This means of communication had led to the process of formulation being at best anecdotal, and at worst moribund. Processes are followed without any articulation of how or why they work. This vernacular approach does not allow for the substitution of a particular ingredient by a new one (in this case cuttlefish bone powder) with a view to that substitution being one that can be relied upon to work. There was a clear need to devise an approach which allowed practitioners to develop formulations in a more efficient way, without losing intuitive means of making evaluative judgements.

It was felt that the alternative, scientific approach would be inaccessible and inappropriate to practitioners. For example, Materials Science has systematic methodologies that lead to the formulations of particular materials. These methodologies are scientific in nature, having the purpose of securing reliable processes of replication, a purpose that is different from the motives for undertaking art production, in which the product itself is normally unique or developed in small batches or editions, requiring flexibility of process, in qualitative terms, above accuracy in terms of replication.

It was decided that the way forward was to put a methodology in the hands of those interested in finding new formulations (i.e. the practitioner of Fine Art and Craft). It was identified that this methodology had to be reliable, auditable, communicable and intuitive; a kind of additional "sense" which the practitioner could use to interpret more clearly the results of experiments in order that the search for formulation could be done efficiently and appropriately in relationship to the end user.

The methodology was developed by a practitioner with advice from artists and engineers whose aim it was to ensure that the above goals were reached. The approach was eventually distilled into a visual model of the materials, expressing them as "microstructure drawings" which show the amounts, shapes and sizes of the ingredients of the formulations. In use (Chapter 7), it was found that this model added to, but did not replace other observations made during formulation, such as the practitioner's judgement of slurry and mould quality. The model drawings were also usefully supplemented by the bar-charts, which show the make-up of the mixtures, and it is acknowledged that slight differences in make-up can be more clearly seen from a bar chart than from a microstructure drawing.

The ability to understand and visualise the behaviour of the material, exposes the interplay of crucial variables within the process such as the ratio of cementitious ingredients : refractory ingredients : water, and the size(s) and shape(s) of aggregate. The understanding of the relative roles of these formulation variables permits the practitioner to vary formulation at will. An analogy might be improvisation in music where variations are made in relationship to crucial variables, which must be understood at a functional level. In the case of sculpture moulds, the work had identified what can and cannot be varied without the structure failing in its functions, that is where change can be rendered. The expression of the successful formulation can be used and developed at different scales of work, adapted to different working conditions as well as formal shapes with different surface qualities.

In this case the drawing method as a means of modelling the material is derived from a rigorous process that accurately and objectively represents the physical phenomenon, unlike a more poetic type of drawing whose accuracy may lie in the representation of something that does not yet exist, or that is a feeling or emotion. The drawing method **accesses** data/information to the artist in a way that is appropriate to their skills and useful to their development but is nonetheless rigorous, objective research and, in this case, is used in conjunction with more conventional representations of research data such as bar charts.

It is this process of adaptation and invention within acknowledged parameters and across discipline boundaries that makes this research so exciting and genuine. It is accepted that the model is incomplete, but it does appear to explain a number of the observations made in the trial-and-error experiments. More than this, it is clear that, armed with the model, it would be possible, with relatively few experiments, to establish the range of acceptable formulations for both bronze and glass moulds, as opposed to identifying a few formulations which perform acceptably. In principle, the approach could then be used to maximise the amount of waste material (in this case cuttlefish bone) which could be added to any mould size or shape.

The generic aspect of the methodology can thus be summarised as identifying the form and function of the individual components and finding a way of expressing this in a visual medium. Formulation then consists of adjusting the relative quantities of the components to obtain a desired set of properties, which, if the model is correct, could be done without the need for any additional experiment. In this particular case, ingredients can be identified as *refractory*, which remain inert up to bronze casting temperatures, or *cementitious*, which includes both plaster and, to a certain extent, China clay. *Water* is also an ingredient which performs the two functions of affecting the consistency of the slurry and participating in the hydration reaction. Findings from the Literature Review indicate that although some, not all, sculpture manuals acknowledge the importance of a proportional relationship between dry ingredients, they do not acknowledge the function of subsets (i.e. cementitious to refractory), but they rarely mention water as a significant aspect of material proportional relationship.

Besides other clay and mould formulations, another example to which the approach might be applied could be the formulation of paint. Here the range of required properties might be entirely different but will involve handling characteristics, such as interaction with brushes, papers and canvases, as well as aesthetic characteristics, such as surface texture once dried, and light reflecting properties such as colour and iridescence. The components will be a vehicle (usually oil, a polymer or water), some pigments (of various colours, sizes and shapes) and possibly some texturisers, for example sand. Again, a model could be devised, which is visual in nature, which allows the practitioner to carry out experiments on effect, using an accessible and intuitive model. The analogy with sculpture mould formulation is not perfect here, and is closer to that raised above for music improvisation – painters do not simply wish variation, but need this to be related to some structure of effects. So, at an aesthetic level, the painter would need first to identify their equivalent of a crucial structure (probably from the language of painting) and render variations from within it.

# Chapter 9. CONCLUSIONS

## 9.1 Restatement of the problem

This research investigates the potential use of cuttlefish bone powder as an ingredient of moulding material for investment casting for bronze and glass. It addresses practitioners of Fine Art and Craft.

The gap in knowledge that the research addresses is identified from two positions within the literature review as well as with reference to the cultural context of the researcher, Malaysia where cuttlefish bone powder is a waste material. This cultural factor acts as an initial catalyst to the investigation, and provides its narrow focus. The two reference points within the literature review are as follows:

- Practitioners of Fine Art and craft communicate process by word of mouth or through craft manuals. This method is as true of contemporary practice as of practice of the past ($14^{th}$ Century Italy) and is essentially vernacular. Processes are followed without any articulation of how or why they work. This vernacular approach does not allow for the substitution of a particular ingredient by a new one (in this case cuttlefish bone powder) with a view to that substitution being one that can be relied upon to work.
- Materials Science has systematic methodologies that lead to the formulations of particular materials. These methodologies are scientific in nature, having the purpose of securing reliable processes of replication, a purpose that is different from the motives for undertaking art production, in which the product itself is

normally unique or developed in small batches, requiring flexibility of process above accuracy in terms of replication.

The problem the researcher faces is therefore twofold:

- To evolve a formulation in which cuttlefish bone powder is a significant ingredient that is sufficiently reliable for the purposes of the artist or crafts person
- To communicate this formulation, along with the methodology that derived it, to the practice/discipline of Fine Art and Craft so that it is plausible and clear to practitioners in the first instance, and auditable by them allowing them to engage with the formulation in a flexible manner and if necessary to develop and improve it for their own purposes. These are more likely to be qualitative than quantitative, e.g. better surface print, adaptable in scale and formal complexity, adaptable to different cultural working conditions.

### 9.2 Conclusions

The conclusions of the research are as follows:

**• There is merit in using the waste material, cuttlefish bone powder, in a moulding process for bronze and glass casting**

The research was initiated through a concern to investigate the potential of cuttlefish bone powder as an ingredient of investment casting for bronze and glass. This concern arose from the cultural context of Malaysia, the home of the researcher, who, as a practising sculptor, raised the issue of replacing expensive imported materials for investment casting by a local recycled product, cuttlefish bone powder. Whereas it was known that cuttlefish bone, taken as a whole, could be used effectively albeit on a small scale, it was not known whether and how it might be used as a crushed ingredient that could replace conventional materials such as grog or molochite. The resulting experimental process, along with the critical investigation of the results of this process, have led to the conclusion that the use of cuttlefish bone powder as a substitute material is both **possible and feasible**.

The potential or **possible use** is achieved by deriving a formulation in which cuttlefish bone powder is a significant ingredient that works at two key stages of the process - the slurry technique stage and the investment casting stage. Clear criteria for each stage are used to evaluate the success or otherwise of a series of experiments that, whilst not exhaustive, are sufficient to make a clear case.

The **feasibility** of the use of cuttlefish bone powder lies at a number of levels, broadly describable as quantitative, qualitative and cultural

• in deriving a formulation in which cuttlefish bone powder is a significant ingredient in terms of its proportion to other ingredients used in the mix (slurry technique stage)

• in evaluating the results of the experimental stages through qualitative criteria such as the feel of the material (creaminess at the slurry technique stage), its capacity to resist heat and the forces of the investment processes, the quality of the resulting print and 'cleanness' and efficiency of departure of the positive from the negative mould.

• in determining the cultural relevance of the research both to the culture of Sculpture/ Craft practice and within the specific geophysical location of Malaysia. Findings from an initial set of interviews 'in the field' both in Malaysia and in Scotland clearly indicate that the use of cuttlefish bone powder as an ingredient within a formulation is not known, but is interesting. Interviews, and the subsequent acquisition of the material by the researcher at the outset of the project, indicate that the material can be sourced with relative ease, crushed and graded efficiently, thus suggesting that the uptake of the results of the research is also feasible, though as yet not fully explored.

• **Whilst researching how this waste material can be used, a methodology has been developed for formulating and communicating the resulting process**

The contemporary aspect of the literature review into how practitioners of Fine Art/ Craft currently communicate process alongside the nature of that process, led to the conclusion that the current method of communication is by word of mouth and that the process itself is unsystematic, i.e. the subject of trial and error procedures undertaken by each individual as a result of imprecise information. Both existing methods of sculpture investment process for bronze and glass and existing methods of the slurry technique for bronze and glass were reviewed from a variety of sources. The investigation into the use of a new ingredient therefore identified another level of research that would need to be addressed as part of the enquiry; the development of a clear and auditable method of both **formulating** and **communicating** the result.

The problem therefore became twofold: to derive the formulation itself, and, alongside this, develop a way of communicating it clearly to the group whom the research addresses - practitioners of the visual arts and craft. This factor has therefore informed the whole methodological approach, which might be described as an extended form of trial and error (as opposed to a systematic empirical scientific study), followed by an analysis of the results of this set of trials and the development of a model to explain the results. The fact that the methodology has been developed by a practitioner indicates that it is accessible and therefore potentially communicable. However, it is recognised that the communicability has yet to be demonstrated, and this is identified as a possible item of further work.

**• That methodology has been used in a critical way, in that the 'extended trial and error process' has been revisited to see what might be improved**

The experimental stage (slurry technique and investment stages) is generative in nature and establishes some experience of the material of cuttlefish bone and some knowledge of what proportions and procedures work or do not work at the two crucial stages, the slurry technique stage in which the mould is manufactured/ fabricated and the investment stage in which the positive is created by subjecting the mould to heat and different types of forces. The resulting 'how' is subjected to critical examination through a second methodological stage that is critical in nature i.e. the development of microstructure drawings that visualise the results of the experimental stage with a degree of accuracy and is refined and practised by the researcher until it becomes an intuitive tool by which the behaviour of formulations can be anticipated through visualising what they look like 'in one's head' or through a sketch version of the more measured/ calculated drawing procedure. This method of visualising the behaviour of the material through a series of variations of materials and their proportions, enables the initial experiments to be revisited and interrogated as to why one formulation works and another does not allowing for an auditing procedure that can easily be understood and, if relevant, appropriated by a practitioner of visual art and craft who is not a trained scientist. The method itself therefore leads to a greater reliability and intuitive control for practitioners.

• **Some insight has been gained into the divergence of motives in the communication of process between engineering and fine art practice**

The need to evolve a methodology that is appropriate to the user group that the research addresses has focused a divergence of motives between research practice for an engineer and that of a craft/ fine art practitioner. This is discussed in part two of the literature review which traces the historical point at which mass production, normally associated with industry, diverges from individual methods of producing bespoke products, currently associated with Craft and Fine Art. The research concludes that, where craft / fine art seeks effects for the purposes of expression, engineering seeks technology for purposes of replication. The vernacular transfer of 'knowhow' is no longer sustainable as the very networks of communication on which it has depended have largely disappeared (family businesses, guilds, ateliers etc.)

It is argued therefore that a negotiated process of developing critical methodologies for fine art and craft in collaboration with engineering provides a way forward in which process in craft and fine art practice may be currently communicated and be allowed to evolve reliably beyond a vernacular process of doing and communication of doing.

## 9.3 Recommendations for future work

Several possible future lines of research have been suggested by this work:

- In the first instance, the research proposes that cuttlefish bone powder can function as a viable and ecological alternative to other ingredients within the investment casting process for bronze and glass. The findings prove that this is indeed possible technically but would need to be tested in the field, within the working practices of fine art and craft practitioners in the cultural context of Malaysia and against economic factors in the acquisition, crushing and grading of the raw material to fully make an ecological claim. In conjunction with this, commercial exploitation of the material would need to be presaged by a sound business case, which recognises the potential market size, market segments (local and international), likely pricing structure, and the costs of, acquisition of the waste material and of production and transportation of powders.
- The methodology is recognised as being accessible, but it has yet to be demonstrated that it is communicable. There is therefore the potential to carry out some experimental work (perhaps through workshops with practitioners and/or students to assess the communicability. This experience could give rise to suggestions for different ways of presenting the methodology, which might include IT techniques. It is not difficult to imagine the existing example being coded into a programme, where, for example the symbols could become computer icons and the mixing and hardening processes could be represented as animations. From there, another step might involve isolating the generic aspects of the methodology and allowing user inputs (for example of the target properties and the properties of the components).

• The research, although directed towards practitioners of Fine Art and Design, addresses a technological process that impacts on but, in this instance, is not central to the creation of the object. However, the methodology proposed in this research of experimentation, visualisation and interrogation can be used in relationship to other types of material technologies that do impact more directly on the meaning of the outcome, for example the instance of the painter dealing in a vocabulary of material-driven effects described in Chapter 8. There are others: the sculptor who chooses a vocabulary of textures and colours within other cast media such as concrete. Technologies of making within Art and Craft are integral to the process by which objects of art and craft make meaning. By visualising process (normally assumed, or invisible, or "hit and miss") the author/artist/ craftsperson is empowered to gain access and understanding into the impact and weight of their intuitive experimental handling. Such an extension would be considerably aided by having the methodology automated in computer software.

• Access to how something has been made is arguably a significant way into understanding the meaning and value of an art and craft outcome, be it object-, installation- or time-based. The exposure of process through methods of visualisation of stages of the process can, in certain circumstances, provide the audience of both art and craft works with a way into experiencing the work itself.

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## Abbreviations

| | |
|---|---|
| ✓ | Achieved evaluation criteria |
| ✗ | Not achieved evaluation criteria |
| Bm | Bronze mould |
| C.clay | China clay |
| C.ctb | Coarse cuttlefish bone |
| C.g | Coarse grog (seive mesh 5 and under) |
| F.bld.sd. | Fine building sand |
| F.c.p | Fine casting plaster |
| F.ctb.p | Fine cuttlefish bone powder |
| F.g | Fine grog (seive mesh 85 and under) |
| g. | Gram |
| G.fibre | Glass fibre |
| Gm | Glass mould |
| G.old m | Glass old mould |
| Kg. | Kilogram |
| Lit. | Litre |
| LKIM | Lembaga Kemajuan Ikan Malaysia (Fisheries Development Authority of Malaysia) |
| Mil. | Millilitres |
| Molt. | Molochite |
| RM | Ringgit Malaysia (Malaysian Ringgit) |
| Sil.sd | Silver sand |
| SIRIM | Standards and Industrial Research Institute of Malaysia |
| UiTM | University Technology Mara |
| Vermicul. | Vermiculite |

## Appendix: 1

## Experiment I

## (Slurry Technique for Bronze Mould)

Cuttlefish Bone Investment Casting Mixture Mould for Bronze Sculpture.(To Identify the Cuttlefish Bone Powder Mixed With the Existing Bronze Mould Material and the Refractory).

Table A1. 1

| Code No. | Mould Weight | Materials Mixture Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm1 | 0.5 kg | 50% F. c. p 0.25kg-250g = 400 Millilitres<br>50% F. ctb, 0.25kg-250g = 350 Millilitres<br>100% 0.5 kg-500g 750 Millilitres<br><br>F.c.p = 250 gm = 250x1.6 = 400 Millilitres.<br>F.ctb.p = 250 gm = 250x1.4 = 350 Millilitres.<br><br>F.c.p = 400/ 750x100 =160/3 =53.3%<br>F.ctb.p = 350/750x100 = 140/3 =46.7%<br>100% | 1.5 Lit.<br>1500ml. | 10 minute stir, very thin mixture, pour in the roller zinc. After 15 minute check , the mixture going to set, but remain a lot of water on the top of the mould. Another 15 min take 1lit. water out from the mould. The mixture is set but still remain 100ml. of water on the top of the set ( wet ) mould. | Very bad mixture mould, because too much water. | The mixture need to be improved, refer to the next experiment Bm2 |

Table A1. 2

| Code No | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm2 | 0.5 kg | 50% F. c. p 0.25kg-250g = 400 Millilitres<br>50% F. ctb. 0.25kg-250g = 350 Millilitres<br>100% 0.5 kg-500g 750 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb p = 250x1.4 = 350 Millilitres<br><br>F.c.p = 400/750x100 = 160/3 = 53.3%<br>F.ctb. p = 350/750x100 = 140/3 = 46.7%<br><br>100% | 0.5 lit.<br>500 ml. | 10 minute stir, the mixture is sign of thick and creamy. Then pour in the roller zinc. Check on another 18 minute, the mixture is ready to set ( wet and soft mould), but remain clear water on the top of the mould. The next check is another 90 minute, the mixture is remain the same and 0.25 ml of water on the top of the mould. The water is increased to 50ml. after next day check. | Very bad mixture mould, still too much water. | The mixture need to be improved, refer to the next experiment Bm3 |

Table A1. 3

| Code no. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm3 | 0.5 kg. | 70% F.c.p 0.35 kg- 350 g = 560 Millilitres<br>30% F. ctb.p 0.15 kg- 150 g = 210 Millilitres<br>100% 0.5 kg- 500 g 770 Millilitres<br><br>F.c.p = 350x1.6 = 560 Millilitres<br>F.ctb. p = 150x1.4 = 210 Millilitres<br><br>F.c.p = 560/770x100 = 5600/77 = 72.7%<br>F.ctb. p = 210/770x100 = 2100/77 = 27.3%<br><br>100% | 0.5 Lit.<br>500 ml. | 10 minute stir, sign of thick mixture, then pour in the roller zinc, next 5 minute check, the mixture is going to set. Another 20 minute check the mixture is remain the same and 0.25 ml of water is remain on the top of the mould. Next 35 minute check the mixture is set and soft mould, remain 0.25 ml. of water. Next day check the water increase to 50ml on the top of the wet and soft mould. | Very bad mixture mould, because too much water. | The mixture need to be improved, refer to the next experiment Bm4 |

Table A1. 4

| Code No | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm4 | 0.5 kg | 50% F. c. p.0.25 kg- 250 g = 400 Millilitres<br>50% F.ctb. 0.25 kg- 250 g = 350 Millilitres<br>100% 0.5 kg- 500 g 750 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 250x1.4 = 350 Millilitres<br><br>F.c.p = 400/750x100 = 160/3 = 53.3%<br>F.ctb.p = 350/750x100 = 140/3 = 46.7% | 0.3 Lit. 300 Ml. | 5 min stir, the mixture turn very thick and very sticky. Pour in the roller zinc. Next 10 minute check, the mixture is set, but very sticky and wet, no water on the mould .Another 40 minute check, the mixture remain the same but very little water on the mould. Next 20 minute check, the mixture is set, still remain very little water on the top of the mould. | Very bad mixture mould, because too little water. | The mixture need to be improved, refer to the next experiment Bm5 |

Table A1. 5

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm5 | 0.5 kg | 50% F. c.p.0.25 kg- 250g = 400 Millilitres<br>50% F. ctb.0.25 kg- 250g = 350 Millilitres<br>100% 0.5 kg-500g 750 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F.ctb.p = 250x1.4 = 350 Millilitres<br><br>F.c.p = 400/750x100 = 160/3 = 53.3%<br>F.ctb.p = 350/750x100 = 140/3 = 46.7%<br><br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture turn creamy, thick and sticky. Then, pour in the roller zinc. 10 minute check, the mixture set but wet, no water on the top of the mould. But later 10 minute check, very little water remain on the top of the mould. Next every 10 minute check for total of 30 minute, the mixture is set but little water remain on the top of the mould. Next day check, 25 ml water on the top of the set mould. | The mixture is good, creamy, thick and sticky. But contain of 25 ml water on the top of the mould. | The mixture need to be improved, refer to the next experiment Bm6. |

Table A1. 6

| Code No | Mould Weight | Material Mixture Weight/ Grams Volume / Millilitres (c.c) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm6 | 0.5 kg | 70% F. c p 0.35 kg- 350g = 560 Millilitres<br>30% F.ctb. 0.15 kg- 150g = 210 Millilitres<br>100% 0.5 kg- 500g 770 Millilitres<br><br>F.c.p = 350x1.6 = 560 Millilitres<br>F.ctb.p = 150x1.4 = 210 Millilitres<br><br>F.c.p = 560/770x100 = 5600/77 = 72.7%<br>F.ctb.p = 210/770x100 = 2100/77 = 27.3%<br><br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture turn very good, creamy and thick. Then, pour in the roller zinc. 10 minute check, the mixture is set and no water on the top of the mould. But, next 10 minute check, very little water on the top of the mould. Every 10 minute for total of 1 hr; check 10 ml of water remain on the top of the mould. After 3 days check, the mixture is completely set, and no water. | The mixture is very good, but still contain water on the top of the mould. | The mixture need to be improved, refer to the next experiment Bm7. |

Table A1. 7

| Code No. | Mould Weight | Materials Mixture Weight/ Grams Volume/ Millilitres (c.c) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm7 | 0.5 kg | 50% F. c. p.0.25 kg- 250g = 400 Millilitres<br>50% F.ctb. 0.25 kg- 250g = 350 Millilitres<br>100% 0.5 kg- 500g 750 Millilitres<br><br>F.c.p = 250x1.6 = 400 Milliliters<br>F.ctb.p = 250x1.4 = 350 Millilitres<br><br>F.c.p = 400/750x100 = 160/3 = 53.3%<br>Fctb.p = 350/750x100 = 140/3 = 46.7% | 0.35 Lit. 350 Ml. | 5 minute stir, the mixture turn very thick, then pour in the roller zinc. 10 minute check, the mixture is set, no water on the top of the mould. Next 10 minute check still the same. Another 10 minute check, very little water on the top of the mould. 90 minute for every 10 minute check, the mixture is set but soft and very little water remain on the top of the mould. | The mixture is very bad, because too thick and very loose. Very little water remain on the top of the mould after 2 hr. minute check. | The mixture need to be improved, refer to the next experiment Bm8. |

Table A1. 8

| Code No | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm8 | 0.5 kg | 75% F. c p.0.375 kg- 375g = 600 Millilitres<br>25% F. ctb.0.125 kg- 125g = 175 Millilitres<br>100% 0.5 kg- 500g 775 Millilitres<br><br>F.c.p = 375x1.6 = 600 Millilitres<br>F.tb.p = 125x1.4 = 175 Millilitres<br><br>F.c.p = 600/775x100 = 2400/31 = 77.4%<br>F.ctb.p = 175/775x100 = 700/31 = 22.6%<br><br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture turn very good, creamy, thick and opaque. Then, pour in the roller zinc. 15 minute check, the bottom part of the mould is hard set compare to the top surface of the mould and remain very little water on the top of the mould. Next 15 minute check, the mixture is completely set, no water and cold mould set. | Very good mixture mould, creamy, thick and opaque No water on the top of the mould. But very cold mould set, not like the ordinary plaster mould is very warm, when it set. | Perfect mixture mould and recommended to be tested in the experiment II. |

able A1. 9

| Code No. | Mould Weight | Materials Mixture Weight/ Gram Volume/ Millilitres (c.c) | Water | Materials Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm9 | 0.5 kg | 50% F.c.p 0.25kg =250g = 400 Millilitres<br>25% F.ctb.p 0.125kg = 125g = 175 Millilitres<br>25% F.grog 0.125kg = 125g = 100 Millilitres<br>100% 0.5kg = 500g = 675 Millilitres<br><br>F.c.p = 250x1.6=400 Ml<br>F.ctb.p=150x1.4=175 Ml<br>F.grog= 150x0.8=100 Ml<br><br>F.c.p=400/675x100= 1600/27=59.3%<br>Fctb.p= 175/675x100= 700/27=25.9%<br>F.grog=100/675x100= 400/27=14.8%<br>100% | 400 Lit. 400 Ml. | 10 min. stir, the mixture turn thick and fine, then pour in roller zinc. 10 min. check, the mixture set but soft and remain very little water on the top of the mould. Next 10 min. check, the mixture is completely set "hard mould" but remain little water another 10 min. check, every thing remain the same. Next 20 min. check remain the same and open the roller zinc, mould set but wet. | The mixture is fine, but remain very little water on the top of the mould. | The mixture need to be improved, refer to the next experiment Bm10. |

Table A1. 10

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm10 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>25% F.ctb. 0.125 kg-125g = 175 Millilitres<br>25% F.grog 0.125 kg-125g = 100 Millilitres<br>100% 0.5 kg-500g 675 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F.ctb. p = 125x1.4 = 175 Millilitres<br>F.grog = 125x0.8 =100 Millilitres<br><br>F.c.p = 400/675x100 = 1600/27 = 59.3%<br>F.ctb.p = 175/675x100 = 700/27 = 25.9%<br>F.grog = 100/675x100 = 400/27 = 14.8%<br><br>100% | 0.35 Lit. 350 Ml. | 5 minute stir, the mixture turn very thick, then pour in the roller zinc. Next 5 minute check the mixture turn creamy. 10 minute check, everything is remain the same. 10 minute check the mixture is slightly set, very soft and little water. 10 minute check, the mixture is set and remain a lot of water on the top of the mould. 20 minute check, the mixture is completely set " hard mould", a lot of water remain. | The mixture is good, but remain a lot of water on the top of the mould. | The mixture need to be improved, refer to the next experiment Bm11. |

Table A1. 11

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm11 | 0.5 kg | ¼% F . c. p. 0.125 kg-125g = 200 Millilitres<br>¼% F. ctb. 0.125 kg-125g = 175 Millilitres<br>¼% F.grog 0.125 kg-125g = 100 Millilitres<br>0.375kg-375g 475 Millilitres<br><br>F.c.p = 125x1.6 = 200 Millilitres<br>F. ctb.p = 125x1.4 = 175 Millilitres<br>F.grog = 125x0.8 = 100 Millilitres<br><br>F.c.p = 200/475x100 = 800/19 = 42.1%<br>F.ctb.p = 175/475x100 = 700/19 = 36.8%<br>F.grog = 100/475x100 = 400/19 = 21.1%<br><br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is very thin, pour in the roller zinc. 10 minute check, plenty of water on the top of the mould. Next 15 minute check, nothing changed and stir one more time in the roller zinc. Next 10 minute check, nothing changed and check on 50 minute later, the mixture is ready to set and a lot of water on the top of the mould. Lastly. 10 minute check, the mixture is set but a lot of water. | Very bad mixture mould and real problem. | The mixture need to be improved, refer to the next experiment Bm12. |

Table A1. 12

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm12 | 0.5 kg. | 60% F. c. p. 0.3 kg-300g = 480 Millilitres<br>20% F. ctb. 0.1 kg-100g = 140 Millilitres<br>20% F.grog 0.1 kg-100g = 80 Millilitres<br>100% 0.5 kg-500g = 700 Millilitres<br><br>F.c.p = 300x1.6 = 480 Millilitres<br>F.ctb. p = 100x1.4 = 140 Millilitres<br>F.grog = 100x0.8 = 08 Millilitres<br><br>F.c.p = 480/700x100 = 480/7 = 68.6%<br>F.ctb.p = 140/700x100 = 140/7 = 20%<br>F.grog = 80/700x100 = 80/7 = 11.4%<br><br>100% | 0.4 Lit. 400 Ml. | 15 minute stir, the mixture turn perfect, creamy, thick and opaque. Then pour in the roller zinc. Next 5 minute check, the mixture is completely set "Hard mould" and no water on the top of the mould, very cold mould set. 25 minute check, everything is set and open the roller zinc. | Very good mixture mould, creamy, thick and opaque. No water on the top of the mould and very cold mould set. | Perfect mixture mould and recommended to be tested in the experiment II |

Table A1. 13

| Code No. | Mould Weight | Mixture Material Weight/ Grams Volume/ Millilitres ( c.c) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm13 | 0.5 kg. | 60% F. c. p. 0.3 kg-300g = 480 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>20% C.grog 0.1 kg-100g = 80 Millilitres<br>100% 0.5 kg-500g 700 Millilitres<br><br>F.c.p = 300x1.6 = 480 Millilitres<br>F.ctb.p = 100x1.4 = 140 Millilitres<br>C.grog = 100x0.8 = 80 Millilitres<br><br>F.c.p = 480/700x100 = 480/7 = 68.6%<br>F.ctb.p = 140/700x100 = 140/7 = 20%<br>C.grog = 80/700x100 = 80/7 = 11.4%<br><br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture turn very perfect, creamy, thick and opaque. Then, pour in the roller zinc. Next 10 minute check, the mixture is completely set "Hard mould" and no water on the top of the mould. Next 5 minute check, everything is set and open out the roller zinc. Cold mould set. | Very good mixture mould, creamy, thick and opaque. No water remain on the top of the set mould and cold mould set. | Perfect mixture mould and recommended to be tested in the experiment II. |

Table A1. 14

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm14 | 0.5 kg | 45% F. c. p. 0.225 kg-225g = 360 Millilitres<br>45% F. ctb. p. 0.225 kg-225g = 315 Millilitres<br>10% C clay 0.05 kg- 50g = 140 Millilitres<br>100% 0.5 kg-500g 815 Millilitres<br><br>F.c.p = 225x1.6 = 360 Millilitres<br>F.ctb.p = 225x1.4 = 315 Millilitres<br>C clay = 50x2.8 = 140 Millilitres<br><br>F.c.p = 360/815x100 = 7200/163 = 44.2%<br>F.ctb.p = 315/815x100 = 6300/163 = 38.7%<br>C.clay = 140/815x100 = 2800/163 = 17.1%<br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture turn good, creamy thick and opaque. Pour in the roller zinc. 10 minute check, the mixture is ready to set, Next 20 minute check, the mixture remain the same. 10 minute later, the mixture is set and very little water on the top of the mould. Next 10 minute check, the mixture is completely set and remain slightly very little water. | The mixture is good, but contain very little water on the top of the mould, make the mould wet and soft. | The mixture need to be improved, refer to the next experiment Bm15. |

TableA1. 15

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm15 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>40% F. ctb. p. 0.2 kg-200g = 280 Millilitres<br>10% C.clay 0.05 kg- 50g = 140 Millilitres<br>100% 0.5 kg-500g 820 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F.ctb.p = 200x1.4 = 280 Millilitres<br>C.clay = 50x2.8 = 140 Millilitres<br><br>F.c.p = 400/820x100 = 2000/41 = 48.8%<br>F.ctb.p = 280/820x100 = 1400/41 = 34.1%<br>C.clay = 140/820x100 = 700/41 = 17.1%<br><br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture turn very good, creamy, thick and opaque, pour in the roller zinc. 10 minute check, the mixture is the same. Another 10 minute check, the mixture is set "Hard mould", but remain very little water on the top of the mould. 10 minute check, the mixture remain the same. Finally, next 10 minute check, the mixture set and no water. | The mixture is good and 20 minute to get the set. But remain water on the top of the mould, another 20 minute check, than no water remain. | This mixture is better than Bm14. the mixture need to be improved, refer to the experiment Bm16. |

Table A1. 16

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm16 | 0.5 kg | 60% F. c. p. 0.3 kg-300g = 480 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>20% C .Clay 0.1 kg-100g = 280 Millilitres<br>100% 0.5 kg-500g 900 Millilitres<br><br>F.c.p = 300x1.6 = 480 Millilitres<br>F.ctb.p = 100x1.4 = 140 Millilitres<br>C.clay = 100x2.8 = 280 Millilitres<br><br>F.c.p = 480/900x100 = 480/9 = 53.3%<br>F.ctb.p = 140/900x100 = 140/9 = 15.6%<br>C.clay = 280/900x100 = 280/9 = 31.1%<br>100% | 0.4 Lit. 400 ml. | 5 minute stir, the mixture turn too thick and no drop from the hand. Pour in the roller zinc. 5 minute check, the mixture is creamy and next 5 minute check, the mixture is ready to set. Next 10 minute check, the mixture is completely set "Hard mould", and no water on the top of the mould. Lastly, 5 minute check, the mixture is set and open from the roller zinc. | Very bad mixture mould, because too thick. | The mixture need to be improved, refer to the next experiment Bm17. |

Table A1. 17

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm17 | 0.5 kg | 60% F. c. p. 0.3 kg-300g = 480 Millilitres<br>30% F . ctb. p. 0.15 kg-150g = 210 Millilitres<br>10% C. Clay 0.05 kg- 50g = 140 Millilitres<br>100% 0.5 kg-500g 830 Millilitres<br><br>F.c.p = 300x1.6 = 480 Millilitres<br>F.ctb.p = 150x1.4 = 210 Millilitres<br>C.clay = 50x2.8 = 140 Millilitres<br><br>F.c.p = 480/830x100 = 4800/83 = 57.8%<br>F.ctb.p = 210/830x100 = 2100/83 = 25.3%<br>C.clay = 50/830x100 = 1400/83 = 16.9%<br>100% | 0.4 Lit. 400mMl. | 10 minute stir, the mixture turn good, creamy, thick and opaque. Pour in the roller zinc. 5 minute check, the mixture is going to set. Another 5 minute check, the mixture is set, but still in soft and wet. 5 minute check, the mixture remain the same. Next 5 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. Open the roller zinc, the mould is slightly warm at the bottom. | Very good mixture mould, creamy, thick and opaque. No water on the top of the mould, and slightly warm mould. | Perfect mixture mould and recommended to be tested in the experiment II. |

Table A1. 18

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm18 | 0.5 kg | 60% F. c. p. 0.3 kg-300g = 480 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>10% F.grog 0.05kg- 50g = 40 Millilitres<br>10% C. clay 0.05kg- 50g = 140 Millilitres<br>100% 0.5 kg-500g 800 Millilitres<br><br>F.c.p = 300x1.6 = 480 Millilitres<br>F.ctb.p = 100x1.4 = 140 Millilitres<br>F.grog = 50x0.8 = 40 Millilitres<br>C. clay = 50x2.8 = 140 Millilitres<br><br>F.c.p = 480/800x100 = 60/1 = 60%<br>F.ctb.p = 140/800x100 = 140/8 = 17.5%<br>F.grog = 40/800x100 = 5/1 = 5%<br>C.clay = 140/800x100 = 180/8 = 17.5%<br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture turn very good and perfect, creamy, thick and opaque. Then , pour in the roller zinc. 10 minute check, the mixture is completely set "Hard mould" and no water on the top of the mould. Slightly warm mould, after open from the roller zinc. | Very perfect mixture mould, only 10 minute the mixture is set and no water remain. | Perfect mixture mould and recommended to be tested in the experiment II. (The same mixture, but different % of mixture material, refer to the experiment Bm23). |

Table A1. 19

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm19 | 0.5 kg | 1/3% F. c. p. 0.167kg-167g = 267.2 Millilitres<br>1/3% F. ctb. p 0.167kg-167g = 233.8 Millilitres<br>1/3% Molt.0.167kg-167g = 167 Millilitres<br><br>668 millilitres<br><br>F.c.p = 167x1.6 = 267.2 Millilitres<br>F.ctb.p = 167x1.4 = 233.8 Millilitres<br>Molt. = 167x1 = 167 Millilitres<br><br>F.c.p = 267.2/668x100 = 6680/167 = 40%<br>F.ctb.p = 233.8/668x100 = 5845/167 = 35%<br>Molt. = 167/668x100 = 4175/167 = 25%<br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture is thin and pour in the roller zinc. 10 minute check the mixture is creamy and thick, next 10 minute check, everything remain the same. Every 10 minute check for 30 minute, the mixture is remain the same and plenty of water remain on the top of the mould. Next day check, the mixture is set and no water. | Very bad mixture mould, because thin mixture and remain plenty of water. Takes 1 day to set. | The mixture need to be improved, refer to the next experiment Bm20. |

Table A1. 20

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm20 | 0.5 kg. | 60% F. c. p. 0.3 kg- 300g = 480 Millilitres<br>20% F. ctb. p. 0.1 kg- 100g = 140 Millilitres<br>20% Molt. 0.1 kg- 100g = 100 Millilitres<br>100% 0.5 kg- 500g 720 Millilitres<br><br>F.c.p = 300x1.6 = 480 Millilitres<br>F.ctb.p = 100x1.4 = 140 Millilitres<br>Molt. = 100x1 = 100 Millilitres<br><br>F.c.p = 480/720x100 = 200/3 = 66.7%<br>F.ctb.p = 140/720x100 = 350/18 = 19.4%<br>Molt. = 100/720x100 = 250/720 = 13.9%<br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture turn good, creamy and thick. Then, pour in the roller zinc. 10 minute check, the mixture is going to set, next 10 minute check, the mixture is going to set and little water on the top of the mould. Another 10 minute check, the mixture is set and remain little water. Next 10 minute check, the mixture is completely set "Hard mould", but slightly water remain. Lastly , 10 minute check, set mould and no water. | The mixture is good, but it takes 50 minute to set and another 5 minute notice no water remain on the top of the mould. | The mixture need to be improved, refer to the next experiment Bm21 |

Table A1. 21

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm21 | 0.5 kg | 65% F. c. p. 0.325 kg-325g = 520 Millilitres<br>10% F. ctb. p 0.05 kg- 50g = 70 Millilitres<br>10% C. ctb. p 0.05 kg- 50g = 80 Millilitres<br>15% Molt. 0.075 kg- 75g = 75 Millilitres<br>100% 0.5 kg-500g 745 Millilitres<br><br>F.c.p = 325x1.6 = 520 Millilitres<br>F.ctb.p = 50x1.4 = 70 millilitres<br>C.ctb.p = 50x1.6 = 80 Millilitres<br>Molt. = 75x1 = 75 Millilitres<br><br>F.c.p = 520/745x100 = 10400/149 = 69.8%<br>F.ctb.p = 70/745x100 = 1400/149 = 9.4%<br>C. ctb = 80/745x100 = 1600/149 = 10.7%<br>Molt. = 75/745x100 = 1500/149 = 10.1% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, creamy, thick and opaque and pour in the roller zinc. 10 minute check, the mixture is sticky and almost set. Next 15 minute check, the mixture is set but soft and no water on the top of the mould. Next 5 minute check, the mixture is completely set "Hard mould" and no water on the top of the mould. Slight warm mould. | Very good mixture mould, but slightly thin. | Perfect mixture mould and recommended to be tested in the experiment II. |

Table A1. 22

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm22 | 0.5 kg | ¼% F. c. p. 0.125 kg-125g = 200 Millilitres<br>¼% F. ctb. p. 0.125 kg-125g = 175 Millilitres<br>¼% C.grog 0.125 kg-125g = 100 Millilitres<br>¼% C. clay 0.125 kg-125g = 350 Millilitres<br>100% 0.5 kg-500g 825 Millilitres<br><br>F.c.p = 125x1.6 = 200 Millilitres<br>F.ctb.p = 125x1.4 = 175 Millilitres<br>C.grog = 125x0.8 = 100 Millilitres<br>C. clay = 125x2.8 = 350 Millilitres<br><br>F.c.p = 200/825x100 = 800/33 = 24.2%<br>F.ctb p = 175/825x100 = 700/33 = 21.2%<br>C.grog = 100/825x100 = 400/33 = 12.1%<br>C. clay = 350/825x100 = 1400/33 = 42.4%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture turn very perfect, creamy, thick and opaque. Then, pour in the roller zinc. 5 minute check, the mixture ready to set and no water on the top of the mould. Next 10 minute check, the mixture is set, no water. Finally, another 5 minute check, the mixture is completely set "Hard mould" and no water remain on the top of the mould. | Very good mixture mould, creamy, thick and opaque. No water remain on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. |

Table A1. 23

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm23 | 0.5 kg | 40%F.c.p 0.2kg-200g= 320 Millilitres<br>25%F.ctb.p 0.125 kg-125g = 175 Millilitres<br>25% F.grog 0.125 kg-125g = 100 Millilitres<br>10% C. clay 0.05 kg- 50g = 140 Millilitres<br>100% 0.5 kg-500g 735 Millilitres<br><br>F.c.p = 200x1.6 = 320 Millilitres<br>F.ctb.p = 125x1.4 = 175 Millilitres<br>F.grog = 125x0.8 = 100 Millilitres<br>C. clay = 50x2.8 = 140 Millilitres<br><br>F.c.p = 320/735x100 = 6400/147 = 43.5%<br>F.ctb.p = 175/735x100 = 3500/147 = 23.8%<br>F.grog = 100/735x100 = 2000/147 = 13.6%<br>C. clay = 140/735x100 = 2800/147 = 19%<br>99.9% | 0.4 Lit. 400 Ml. | 5 min stir, the mixture turn perfect, creamy, thick and opaque and then pour in the roller zinc. Next 10 minute check, the mixture is ready to set and no water on the top of the mould. Lastly 5 minutes check the mixture is completely set "Hard mould", no water on the top of the mould and take out from the roller zinc. Cold mould set. | Very good mixture mould. Creamy thick and opaque. Take 15 minute to set. | Perfect mixture mould and recommended to be tested in the experiment II. (Same mixture in the experiment Bm17, but different % of mixture materials). |

Table A1. 24

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm24 | 0.5 kg | 30% F. c. p. 0.15 kg-150g = 240 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>20% C. ctb. p. 0.1 kg-100g = 160 Millilitres<br>20% Molt.0.1 kg-100g = 100 Millilitres<br>10% C. clay 0.05kg- 50g = 140 Millilitres<br>100% 0.5 kg-500g 780 Millilitres<br>F.c.p = 150x1.6 = 240 Millilitres<br>F.ctb.p = 100x1.4 = 140 Millilitres<br>C.ctb.p = 100x1.6 = 160 Millilitres<br>Molt. = 100x1 = 100 Millilitres<br>C. clay = 50x2.8 = 140 Millilitres<br>F.c.p = 240/780x100 = 2400/78 = 30.8%<br>F.ctb.p =140/780x100 = 1400/78 = 18%<br>C. ctb.p = 160/780x100 = 1600/78 = 20.5%<br>Molt. = 100/780x100 = 1000/78 = 12.8%<br>C. clay = 50/780x100 = 1400/78 = 17.9% = 100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture turn perfect, creamy, thick and opaque and pour in the roller zinc. 10 minute check, the mixture is ready to set. Next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould, take the mixture mould out from the roller zinc. | Very good mixture mould, creamy, thick and opaque. Take 20 minute to set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. |

Table A1. 25

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm25 | 0.5 kg | 30% F. c. p. 0.15 kg-150g = 240 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>20% F. bld. sd. 0.1 kg-100g = 80 Millilitres<br>10% C. clay 0.05 kg- 50g = 140 Millilitres<br>20% C. ctb. p. 0.1 kg-100g = 160 Millilitres<br>100% 0.5 kg-500g 760 Millilitres<br>F.cp. = 150x1.6 = 240 Millilitres<br>F. ctb. p =100x1.4 = 140 Millilitres<br>F. bld. sd. = 100x0.8 = 80 Millilitres<br>C. clay = 50x2.8 = 140 Millilitres<br>C. ctb. p = 100x1.6 = 160 Millilitres<br>F.c.p = 240/760x100 = 600/19 = 31.6%<br>F. ctb. p = 140/760x100 = 350/19 = 18.4%<br>F. bld. sd = 80/760x100 = 200/19 = 10.5%<br>C.clay = 140/760x100 = 350/19 = 18.4%<br>C. ctb. p = 160/760x100 = 400/19 = 21.1%<br>100 % | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture turn perfect, creamy, thick and opaque, pour in the roller zinc. 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. Take the mixture mould out from the roller zinc and cold mould set. | Very good mixture mould, creamy, thick and opaque. Take 10 minute to set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. |

Table A1. 26

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm26 | 0.5 kg | ¼% F. c. p. 0.125 kg-125g = 200 Millilitres<br>¼% F. ctb. p. 0.125 kg-125g = 175 Millilitres<br>¼% Molt. 0.125 kg-125g = 125 Mililitres<br>¼% F. bld. sd.1.125 kg-125g = 100 Millilitres<br>100% 0.5 kg-500g 600 Millilitres<br><br>F.c.p = 125x1.6 = 200 Millilitres<br>F. ctb. p = 125x1.4 = 175 Millilitres<br>Molt. = 125x1 = 125 Millilitres<br>F. bld. sd. = 125x0.8 = 100 Millilitres<br><br>F.c.p = 200/600x100 = 200/6 = 33.3%<br>F. ctb. p = 175/600x100 = 175/6 = 29.2%<br>Molt. = 125/600x100 = 125/6 = 20.8%<br>F. bld. sd. = 100/600x100 = 100/6 = 16.7%<br><br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture is thin, pour in the roller zinc. Next 10 minute check, the mixture is not set and a lot of water on the top of the mould. Next 30 minute check, everything remain the same. Another 85 minute check, the mixture is set but remain 175 ml; of water out from the roller zinc. Lastly check, the mixture is set "Hard mould". | Very bad mixture mould, take 125 minute to set the mixture mould and remain 175 ml; of water. | The mixture need to be improved, refer to the next experiment Bm27 |

TableA1. 27

| Code No. | Mould Weight | Mixture Material Weight/ Grams Volume/ Millilitres c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm27 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>20% Molt.0.1 kg-100g = 100 Millilitres<br>10% F. bld. sd.0.05kg- 50g = 40 Millilitres<br>100% 0.5 kg-500g 680 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>Molt. = 100x1 = 100 Millilitres<br>F. bld. sd. = 50x0.8 = 40 Millilitres<br><br>F.c.p = 400/680x100 = 1000/17 = 58.8%<br>F. ctb. p = 140/680x100 = 350/17 = 20.6%<br>Molt. = 100/680x100 = 250/17 = 14.7%<br>F. bld. sd. = 40/680x100 = 100/17 = 5.9%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, pour in the roller zinc. Next 5 minute check, the mixture is going to set and next 10 minute check, the mixture is set, but remain little water on the top of the mould. 10 minute check, everything is the same. Finally, 10 minute check the mixture is completely set "Hard mould" and slightly very little water on the top of the mould. | Very bad mixture mould, because remain slightly very little water on the top of the mould. | The mixture need to be improved, refer to the next experiment Bm28. |

Table A1. 28

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm28 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>10% F. ctb. p. 0.05 kg- 50g = 70 Millilitres<br>40% Molt. 0.2 kg-200g = 200 Millilitres<br>10% F. bld. sd. 0.05 kg- 50g = 40 Millilitres<br>100% 0.5 kg-500g 630 Millilitres<br><br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 50x1.4 = 70 Millilitres<br>Molt. = 200x1 = 200 Millilitres<br>F. bld. sd. = 50x0.8 = 40 Millilitres<br><br>F.c.p = 320/630x100 = 3200/63 = 50.8%<br>F. ctb. p = 70/630x100 = 700/63 = 11.1%<br>Molt. = 200/630x100 = 2000/63 = 31.7%<br>F. bld. sd. = 40/630x100 = 400/63 = 6.4%<br><br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture is good, creamy, thick and opaque, pour in the roller zinc. Next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Very good mixture mould, creamy, thick and opaque. Take 10 minute to set the mixture and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. |

Table A1. 29

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm29 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>25% F. ctb. p 0.125 kg-125g = 175 Millilitres<br>25% F. bld. sd.0.125 kg-125g = 100 Millilitres<br>100% 0.5 kg-500g 675 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 125x1.4 = 175 Millilitres<br>F. bld. sd. = 125x0.8 = 100 Millilitres<br><br>F.c.p = 400/675x100 = 1600/27 = 59.3%<br>F. ctb. p = 175/675x100 = 700/27 = 25.9%<br>F. bld. sd. = 100/675x100 = 400/27 = 14.8%<br><br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture thick, pour in the roller zinc. 10 minute check, no sign of set. So, stir one more time in the roller zinc. 10 minute check, nothing changed. Next 10 minute check, the mixture is completely set, but a lot of water on the top of the mould. Lastly, 70 minute check, the mixture is completely set "Hard mould", no water. | Very bad mixture, the mixture takes 40 minute to set and remain a lot of water on the top of the mould. Then, another 70 minute check, the mixture is set and no water. | The mixture need to be improved, by adding another material, refer to the next experiment Bm30. |

Table A1. 30

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm30 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>25% F. ctb. p. 0.125 kg-125g = 175 Millilitres<br>25% F. bld.sd 0.125 kg-125g = 100 Millilitres<br>10% C. clay 0.05 kg- 50g = 140 Millilitres<br>100% 0.5 kg-500g 735 Millilitres<br><br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 125x1.4 = 175 Millilitres<br>F. bld. sd. = 125x0.8 = 100 Millilitres<br>C. clay = 50x2.8 = 140 Millilitres<br><br>F.c.p = 320/735x100 = 6400/147 = 43.5%<br>F. ctb. p = 175/735x100 = 3500/147 = 23.8%<br>F. bld. sd. = 100/735x100= 2000/147 = 13.6%<br>C. clay = 140/735x100 = 2800/147 = 19%<br>99.9% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture is good, creamy, thick and opaque, then pour in the roller zinc. Next 10 minute check, the mixture is completely set ( soft mould), no water on the top of the mould. Next 5 minute check, the mixture is completely set "Hard mould", no water and slight warm mould set. | Very good mixture mould, creamy, thick and opaque. The mixture takes 15 minute to hardly set mould and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. |

Table A1. 31

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm31 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>20% C.grog 0.1 kg-100g = 80 Millilitres<br>10% C. clay 0.05 kg- 50g = 140 Millilitres<br>100% 0.5 kg-500g 760 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>C.grog = 100x0.8 = 80 Millilitres<br>C. clay = 50x2.8 = 140 Millilitres<br><br>F.c.p = 400/760x100 = 1000/19 = 52.6%<br>F. ctb. p = 140/760x100 = 350/19 = 18.4%<br>C.grog = 80/760x100 = 200/19 = 10.5%<br>C. clay = 140/760x100 = 350/19 = 18.4%<br><br>99.9% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture turn good, creamy, thick and opaque, pour in the roller zinc. Next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould | Very good mixture mould, creamy, thick and opaque. The mixture takes 10 minute to set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II, (same material mixture in the experiment Bm22, but different % of the material mixture ). |

Table A1. 32

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Bm32 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>20% F. bld. sd. 0.1 kg-100g = 80 Millilitres<br>10% C. clay 0.05 kg- 50g = 140 Millilitres<br>100% 0.5 kg-500g 760 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>F. bld. sd. = 100x0.8 = 80 Millilitres<br>C. clay = 50x2.8 = 140 Millilitres<br><br>F.c.p = 400/760x100 = 1000/19 =52.6%<br>F. ctb. p = 140/760x100 = 350/19 = 18.4%<br>F. bld. sd. = 80/760x100 = 200/19 = 10.5%<br>C. clay = 140/760x100 = 350/19 =18.4%<br><br>99.9% | 0.4 Lit 400 Ml | 5 minute stir, the mixture is turn good, creamy, thick and opaque, pour in the roller zinc. Next 10 minute check, the mixture is ready to set and next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Very good mixture mould, creamy, thick and opaque. The mixture take 20 minute to set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. ( Same material mixture in the experiment Bm30, but different % of the material mixture ). |

## Appendix: 2

## Experiment I

## (Slurry Technique for Glass Moulds)

Cuttlefish Bone Investment Casting Mixture Mould for Glass Sculpture. (To Identify the Cuttlefish Bone Powder Mixed With the Existing Glass Mould Materials and the Refractory).

Table A2. 1

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm1 | 0.5 kg | 55% F. c. p. 0.275 kg-275g = 440 Millilitres<br>15% F. ctb. p. 0.075 kg- 75g = 105 Millilitres<br>10% Silv. sd. 0.05 kg- 50g = 40 Millilitres<br>15% F.grog 0.075 kg- 75g = 60 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>100% 0.5 kg-500g 895 Millilitres<br><br>F.c.p = 275x1.6 = 440 Millilitres<br>F. ctb. p = 75x 1.4 = 105 Millilitres<br>Silv. sd. = 50x0.8 = 40 Millilitres<br>F.grog = 75x0.8 = 60 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br><br>F.c.p = 440/895x100 = 44000/895 = 49.2%<br>F. ctb. p = 105/895x100 = 10500/895 = 11.7%<br>Silv. sd. = 40/895x100 = 4000/895 = 4.5%<br>F.grog = 60/895x100 = 6000/895 = 6.7%<br>Vermicul. = 250/895x100 = 25000/895 = 27.9%<br><br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, creamy, thick and opaque, pour in the roller zinc. Next 10 minute check, the mixture is set and no water on the top of the mould. Finally, 5 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. Cold mould set. | Very good mixture mould, creamy thick and opaque. 15 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the next experiment II. Good for glass investment casting mould. |

Table A2. 2

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm2 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>20% F. ctb. p 0.1 kg-100g = 140 Millilitres<br>5% Silv. sd. 0.025 kg- 25g = 20 Millilitres<br>20% F.grog 0.1 kg-100g = 80 Millilitres<br>5% Vermicul.0.025kg- 25g = 250 Millilitres<br>100% 0.5 kg-500g 890 millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>Silv. sd. = 25x0.8 = 20 Millilitres<br>F.grog = 100x0.8 = 80 Millilitres<br>Vermicult. = 25x10 = 250 Millilitres<br><br>F.c.p = 400/890x100 = 4000/89 = 44.9%<br>F. ctb. p = 140/890x100 = 1400/89 = 15.7%<br>Silv. sd. = 20/890x100 = 200/89 = 2.2%<br>F.grog = 80/890x100 = 800/89 = 9%<br>Vermicult. = 250/890x100 = 2500/89 = 28.1%<br>99.9% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, creamy, thick and opaque, pour in the roller zinc. Next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. Cold mould set. | Very good mixture mould, creamy, thick and opaque, 10 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Good for glass investment casting mould. |

Table A2. 3

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm3 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>20% Flint 0.1 kg-100g = 140 Millilitres<br>5% C. clay 0.025 kg- 25g = 70 Millilitres<br>5% F.grog 0.025 kg- 25g = 20 Millilitres<br>100% 0.5 kg-500g 770 Millilitres<br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>Flint = 100x1.4 = 140 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>F.grog = 25x0.8 = 20 Millilitres<br>F.c.p = 400/770x100 = 4000/77 = 51.9%<br>F. ctb. p = 140/770x100 = 1400/77 = 18.2%<br>Flint =140/770x100 = 1400/77 = 18.2%<br>C. clay = 70/770x100 =700/77 = 9.1%<br>F.grog = 20/770x100 = 200/77 = 2.6%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, creamy, thick and opaque, pour in the roller zinc. Next 10 minute check, is completely set "hard mould', no water on the top of the mould. | Very good mixture mould, creamy, thick and opaque, 10 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Good for glass investment casting mould. |

Table A2. 4

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm4 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>15% F. ctb. p. 0.075 kg- 75g = 105 Millilitres<br>15% Flint 0.075 kg- 75g = 105 Millilitres<br>5% C. clay 0.025 kg- 25g = 70 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>10% F.grog 0.05 kg- 50g = 40 Millilitres<br>100% 0.5 kg-500g 970 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 75x1.4 = 105 Millilitres<br>Flint = 75x1.4 = 105 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br>F.grog = 50x0.8 = 40 Millilitres<br><br>F.c.p = 400/970x100 = 4000/97 = 41.2%<br>F. ctb. p = 105/970x100 = 1050/97 = 10.8%<br>Flint = 105/970x100 = 1050/97 = 10.8%<br>C. clay = 70/970x100 = 700/97 = 7.2%<br>Vermicul. = 250/970x100 = 2500/97 = 25.8%<br>F.grog = 40/970x100 = 400/97 = 4.1%<br>99.9% | 0.4 Lit.<br>400 Ml. | 5 minute stir, the mixture is bad, too thick, pour in the roller zinc. Next 10 minute check, the mould is completely set "Hard mould", no water on the top of the mould. | Very bad mixture mould, too thick, although 10 minute the mixture set and no water on the top of the mould. | The mixture need to be improved, refer to the next experiment Gm5. |

Table A2. 5

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm5 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>30% F. ctb. p. 0.15 kg-150g = 210 Millilitres<br>10% Flint 0.05 kg- 50g = 70 Millilitres<br>5% C. clay 0.025 kg- 25g = 70 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>10% F.grog 0.05 kg- 50g = 40 Millilitres<br>100% 0.5 kg-500g 960 Millilitres<br><br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 150x1.4 = 210 Millilitres<br>Flint = 50x1.4 = 70 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br>F.grog = 50x0.8 = 40 Millilitres<br><br>F.c.p = 320/960x100 = 3200/96 = 33.3%<br>F. ctb. p = 210/960x100 = 2100/96 = 21.9%<br>Flint = 70/960x100 = 700/96 = 7.3%<br>C. clay = 70/960x100 = 700/96 = 7.3%<br>Vermicul. = 250/960x100 = 2500/96 = 26%<br>F.grog = 40/960x100 = 400/96 = 4.2%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, creamy but very thick, pour in the roller zinc. Next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | The mixture is creamy, but very thick. A lot of air hole in the mould, which is allowed the unused melting glass and effect to the sculpture form. | Not very good mixture mould and need to be improved, refer to the next experiment Gm6. |

Table A2. 6

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm6 | 0.5 kg | 30% F. c. p. 0.15 kg-150g = 240 Millilitres<br>30% F. ctb. p. 0.15 kg-150g = 210 Millilitres<br>15% Flint 0.075 kg- 75g = 105 Millilitres<br>5% C clay 0.025 kg- 25g = 70 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>15% F.grog 0.075 kg- 75g = 60 Millilitres<br>100% 0.5 kg-500g 935 Millilitres<br>F.c.p = 150x1.6 = 240 Millilitres<br>F. ctb. p = 150x1.4 = 210 Millilitres<br>Flint = 75x1.4 = 105 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br>F.grog = 75x0.8 = 60 Millilitres<br>F.c.p = 240/935x100 = 4800/187 = 25.7%<br>F. ctb. p = 210/935x100 = 4200/187 = 22.5%<br>Flint = 105/935x100 = 2100/187 = 11.2%<br>c. clay = 70/935x100 = 1400/187 = 7.5%<br>Vermicul. = 250/935x100 = 5000/187 = 26.7%<br>F.grog = 60/935x100 = 1200/187 = 6.4%<br><br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, creamy, thick and opaque, pour in the roller zinc. Next 10 minute check, the mixture is set "Soft mould", no water on the top of the mould. Next 5 minute check, everything remain the same. Lastly, 5 minute check, the mixture is set "Hard mould", no water on the top of the mould. | Very good mixture mould, creamy, thick and opaque. 20 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. |

Table A2. 7

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm7 | 0.5 kg | ¼% F. c. p. 0.125 kg-125g = 200 Millilitres<br>¼% F. ctb. p. 0.125 kg-125g = 175 Millilitres<br>¼% Flint 0.125 kg-125g = 175 Millilitres<br>¼% F.grog 0.125 kg-125g = 100 Millilitres<br>100% 0.5 kg-125g 650 Millilitres<br>F.c.p = 125x1.6 = 200 Millilitres<br>F. ctb. p = 125x1.4 = 175 Millilitres<br>Flint = 125x1.4 = 175 Millilitres<br>F.grog = 125x0.8 = 100 Millilitres<br>F.c.p = 200/650x100 = 400/13 = 30.8%<br>F. ctb. p = 175/650x100 =350/13 = 26.9%<br>Flint = 175/650x100 = 350/13 = 26.9%<br>F.grog = 100/650x100 = 200/13 = 15.4% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is "thin", pour in the roller zinc. Next 10 minute check, nothing sign of set, remain a lot of water on the top of the mould. Next 15 minute check, the mixture is set "soft mould" and a lot of water on the top of the mould. Lastly, next 15 minute check, the mixture is set "Hard mould" but remain 50ml of water and take out of the roller zinc. | Very bad mixture mould, thin. 45 minute the mixture set "Hard mould", but remain 50 ml of water on the top of the mould. | The mixture need to be improved, refer to the next experiment Gm8. |

Table A2. 8

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm8 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>20% Flint 0.1 kg-100g = 140 Millilitres<br>20% F.grog 0.1 kg-100g = 80 Millilitres<br>100% 0.5 kg-500g 680 Millilitres<br><br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>Fliunt = 100x1.4 = 140 Millilitres<br>F.grog = 100x0.8 = 80 Millilitres<br><br>F.c.p = 320/680x100 = 800/17 = 47.1%<br>F. ctb. p = 140/680x100 = 350/17 = 20.6%<br>Flint = 140/680x100 = 350/17 = 20.6%<br>F.grog = 80/680x100 = 200/17 = 11.7%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, Creamy, thick and opaque, pour in the roller zinc. Next 10 minute check, the mixture is going to set, and next 10 minute check, completely set, no water on the top of the mould, wait and finally check for another 10 minute, the mixture is completely set "Hard mould", no water on the top of the mould. | Good mixture mould, 30 minute set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Good for slumping and fusing glass mould or inner layer mould. |

Table A2. 9

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm9 | 0.5 kg | 45% F. c. p. 0.225 kg-225g = 360 Millilitres<br>15% F. ctb . p. 0.075 kg- 75g = 105 Millilitres<br>15% Silv. sd. 0.075 kg- 75g = 60 Millilitres<br>15% G. old.m. 0.075 kg- 75g = 150 Millilitres<br>10% C. clay 0.05 kg- 50g = 140 Millilitres<br>100% 0.5 kg-500g 815 Millilitres<br><br>F.c.p = 225x1.6 = 360 Millilitres<br>F. ctb. p = 75x1.4 = 105 Millilitres<br>Silv. sd. = 75x0.8 = 60 Millilitres<br>G. old m. = 75x2 = 150 Millilitres<br>C. clay = 50x2.8 = 140 Millilitres<br><br>F.c.p = 360/815x100 = 7200/163 = 44.2%<br>F. ctb. p = 105/815x100 = 2100/163 = 12.9%<br>Silv. sd. = 60/815x100 = 1200/163 = 7.4%<br>G. old m. = 150/815x100 = 3000/163 = 18.4%<br>C. clay = 140/815x100 = 2800/163 = 17.2%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, creamy thick and opaque, pour in the roller zinc. Next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Very good mixture mould, creamy thick and opaque. 10 minute the mixture set and no water on the top of the mould | Perfect mixture mould and recommended to be tested in the experiment II. Good for glass investment casting mould. |

Table A2. 10

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm10 | 0.5 kg | 30% F. c. p. 0.15 kg-150g = 240 Millilitres<br>30% F. ctb. p. 0.15 kg-150g = 210 Millilitres<br>10% Flint 0.05 kg- 50g = 70 Millilitres<br>10% Silv. Sd. 0.05 kg- 50g = 40 Millilitres<br>10% G. old m 0.05 kg- 50g = 100 Millilitres<br>5% C. clay 0.025 kg- 25g = 70 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>100% 0.5 kg-500g 980 Millilitres<br><br>F.c.p = 150x1.6 = 240 Millilitres<br>F. ctb. p = 150x1.4 = 210 Millilitres<br>Flint = 50x1.4 = 70 Millilitres<br>Silv. sd. = 50x0.8 = 40 Millilitres<br>G. old m. = 50x2 =100 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>Vermicul. = 25x10 =250 Millilitres<br><br>F.c.p = 240/980x100 = 1200/49 = 24.5%<br>F. ctb. p = 210/980x100= 1050/49 = 21.4%<br>Flint = 70/980x100 = 350/49 = 7.1%<br>Silv. sd. = 40/980x100 = 200/49 = 4.1%<br>G. old m. = 100/980x100 = 500/49 = 10.2%<br>C. clay = 70/980x100 = 350/49 = 7.1%<br>Vermicul. = 250/980x100 =1250/49 =25.5%<br>99.9% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is too thick, not really good mixture, pour in the roller zinc. Next 5 minute check, the mixture is almost set and next 5 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Very bad mixture mould, too thick mixture materials, need to be reduced the certain %. | The mixture need to be improved, refer to the next experiment Gm11. |

Table A2. 11

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm11 | 0.5 kg | 40% F .c. p. 0.2 kg-200g = 320 Millilitres<br>30% F. ctb. p. 0.15 kg-150g = 210 Millilitres<br>5% Flint 0.025 kg- 25g = 35 Millilitres<br>10% Silv. Sd. 0.05 kg- 50g = 40 Millilitres<br>5% G. old m. 0.025 kg- 25g = 50 Millilitres<br>5% C. clay 0.025 kg- 25g = 70 Millilitres<br>5% Vermicul.0,025 kg- 25g =250 Millilitres<br>100% 0.5 kg-500g 975 Millilitres<br><br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 150x1.4 = 210 Millilitres<br>Flint = 25x1.4 = 35 Millilitres<br>Silv. sd. = 50x0.8 = 40 Millilitres<br>G. old m. = 25x2 = 50 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br><br>F.c.p = 320/975x100 = 1280/39 = 32.8%<br>F. ctb. p = 210/975x100 = 840/39 = 21.5%<br>Flint = 35/975x100 = 140/39 = 3.6%<br>Silv. sd. = 40/975x100 = 160/39 = 4.1%<br>G. old m. = 50/975x100 = 200/39 = 5.1%<br>C. clay = 70/975x100 = 280/39 = 7.2%<br>Vermicul. = 250/975x100 = 1000/39 = 25.6%<br>99.9% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is bad, too thick, pour in the roller zinc. Next 10 minute check, the mixture is completely set "Hard mould" and no water on the top of the mould. | Very bad mixture mould, too thick mixture materials and need to be reduced the certain %. | The mixture need to be improved, refer to the next experiment Gm12. |

Table A2. 12

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm12 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>10% Flint 0.05 kg- 50g = 70 Millilitres<br>10% Silv. Sd. 0.05 kg- 50g = 40 Millilitres<br>10% G. old m. 0.05 kg- 50g = 100 Millilitres<br>5% C. clay 0.025 kg- 25g = 70 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>100% 0.5 kg-500g 990 millilitres<br><br>F.c. p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>Flint = 50x1.4 = 70 Millilitres<br>Silv. sd. = 50x0.8 = 40 Millilitres<br>G. old m. = 50x2 = 100 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>Vermicul. = 25x 10 = 250 Millilitres<br><br>F.c.p = 320/990x100 = 3200/99 = 32.3%<br>F. ctb. p = 140/990x100 = 1400/99 = 14.1%<br>Flint = 70/990x100 = 700/99 = 7.1%<br>Silv. sd. = 40/990x100 = 400/99 = 4.1%<br>G. old m. = 100/990x100 = 1000/99 = 10.1%<br>C. clay = 70/990x100 = 700/99 = 7.1%<br>Vermicul. = 250/990x100 = 2500/99 = 25.2%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, creamy, thick and opaque, pour in the roller zinc. Next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Good mixture mould, creamy, thick and opaque. 10 minute the mixture is set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Good for glass investment casting mould. |

Table A2. 13

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm13 | 0.5 kg | 25% F. c. p. 0.125 kg-125g = 200 Millilitres<br>25% F. ctb. p 0.125 kg-125g = 175 Millilitres<br>25% Flint 0.125 kg-125g = 175 Millilitres<br>25% Silv. Sd. 0.125 kg-125g = 100 Millilitres<br>100% 0.5 kg-500g = 650 Millilitres<br><br>F.c.p = 125x1.6 = 200 Millilitres<br>F. ctb. p = 125x1.4 = 175 Millilitres<br>Flint = 125x1.4 = 175 Millilitres<br>Silv. sd. = 125x0.8 = 100 Millilitres<br><br>F.c.p = 200/650x100 = 400/13 = 30.8%<br>F. ctb. p = 175/650x100 = 350/13 = 26.9%<br>Flint = 175/650x100 = 350/13 = 26.9%<br>Silv. sd. = 100/650x100 = 200/13 = 15.4%<br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture is very bad, too thin, pour in the roller zinc. 20 minute check, the mixture is completely set, but remain a lot of water on the top of the mould. | Very bad mixture mould, too thin. 20 minute the mixture set and remain a lot of water on the top of the mould. | The mixture need to be improved, refer to the next experiment Gm14. |

Table A2. 14

| Code No. | Mould weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm14 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>30% Flint 0.15 kg-150g = 210 Millilitres<br>10% Silv. Sd. 0.05 kg- 50g = 40 Millilitres<br>100% 0.5 kg-500g 710 Millilitres<br><br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>Flint = 150x1.4 = 210 Millilitres<br>Silv. sd. = 50x0.8 = 40 Millilitres<br><br>F. c.p = 320/710x100 = 3200/71 = 45.1%<br>F. ctb. p = 140/710x100 = 1400/71 = 19.7%<br>Flint = 210/710x100 = 2100/71 = 29.6%<br>Silv. sd. = 40/710x100 = 400/71 = 5.6%<br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture is bad, thin and pour in the roller zinc. Next 20 minute check, the mixture is set "Hard mould", no water on the top of the mould. | Very bad mixture mould, thin mixture and 30 minute the mixture set, no water on the top of the mould. | The mixture need to be improved, refer to the next experiment Gm15. |

Table A2. 15

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm15 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>10% F. ctb. p. 0.05 kg- 50g = 70 Millilitres<br>30% Flint 0.15 kg- 150g = 210 Millilitres<br>10% Silv. Sd. 0.05 kg- 50g = 40 Millilitres<br>100% 0.5 kg-500g 720 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 50x1.4 = 70 Millilitres<br>Flint = 150x1.4 = 210 Millilitres<br>Silv. sd. = 50x0.8 = 40 Millilitres<br><br>F.c.p = 400/720x100 = 500/9 = 55.5%<br>F. ctb. p = 70/720x100 = 175/18 = 9.7%<br>Flint = 210/720x100 = 175/6 = 29.2%<br>Silv. sd. = 40/720x100 = 50/9 = 5.6%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is bad, thin and pour in the roller zinc. Next 20 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Very bad mixture mould, thin, 25 minute the mixture set and no water on the top of the mould. | The mixture need to be improved, refer to the next experiment Gm16. |

Table A2. 16

| Code No. | Mould Weight | Material Mixture Weight/ grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm16 | 0.5 kg | 60% F. c. p. 0.3 kg-300g = 480 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>10% Flint 0.05 kg-50g = 70 Millilitres<br>10% Silv. Sd. 0.05 kg-50g = 40 Millilitres<br>100% 0.5 kg-500g 730 Millilitres<br><br>F.c.p = 300x1.6 = 480 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>Flint = 50x1.4 = 70 Millilitres<br>Silv. sd. = 50x0.8 = 40 Millilitres<br><br>F.c.p = 480/730x100 = 4800/73 = 65.7%<br>F. ctb. p = 140/730x100 = 1400/73 = 19.2%<br>Flint = 70/730x100 = 700/73 = 9.6%<br>Silv. sd. = 40/730x100 = 400/73 = 5.5%<br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture is good, creamy, thick and opaque and pour in the roller zinc. Next 15 minute check, the mixture is ready to set, no water on the top of the mould. Next 5 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Good mixture mould, 20 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. (This mixture mould is good for slumping and fusing glass mould only ). |

Table A2. 17

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm17 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>20% Flint 0.1 kg-100g = 140 Millilitres<br>20% G. old m. 0.1 kg-100g = 200 Millilitres<br>100% 0.5 kg-500g 800 Millilitres<br><br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>Flint = 100x1.4 = 140 Millilitres<br>G. old m. = 100x2 = 200 Millilitres<br><br>F.c.p = 320/800x100 = 40/1 = 40%<br>F. ctb.p = 140/800x100 = 35/2 = 17.5%<br>Flint = 140/800x100 = 35/2 = 17.5%<br>G. old m. = 200/800x100 = 25/1 = 25%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is very good, creamy, thick and opaque, pour in the roller zinc. Next 20 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Very good mixture mould, creamy, thick and opaque and 20 minute the mixture set, no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Good for glass investment casting mould. |

Table A2. 18

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm18 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>30% F. ctb. p. 0.15 kg-150g = 210 Millilitres<br>30% Flint 0.15 kg-150g = 210 Millilitres<br>100% 0.5 kg-500g 740 Millilitres<br><br>F. c,p = 200x1,6 = 320 Millilitres<br>F. ctb. p = 150x1.4 = 210 Millilitres<br>Flint = 150x1.4 = 210 Millilitres<br><br>F.c.p = 320/740x100 = 1600/37 = 43.2%<br>F.ctb. p = 210/740x100 = 1050/37 = 28.4%<br>Flint = 210/740x100 = 1050/37 = 28.4%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, creamy, thick and opaque, pour in the roller zinc. Next 15 minute check, the mixture is going to set, next 10 minute check, the mixture is still the same, going to set. Lastly, 10 minute check, the mixture is set, but remain very little water on the top of the mould. | Very good mixture mould, creamy, thick and opaque, but 35 minute the mixture set and remain very little water on the top of the mould. | The mixture need to be improved, refer to the next experiment Gm19 |

Table A2. 19

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm19 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>25% F. ctb. p. 0.125 kg-125g = 175 Millilitres<br>25% Flint 0.125 kg-125g = 175 Millilitres<br>100% 0.5 kg-500g 750 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 125x1.4 = 175 Millilitres<br>Flint = 125x1.4 = 175 Millilitres<br><br>F.c.p = 400/750x100 = 160/3 = 53.3%<br>F. ctb. p = !75/750x100 = 70/3 = 23.3%<br>Flint = 175/750x100 = 70/3 = 23.3%<br>99.9% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is bad, very thin, pour in the roller zinc. Next 10 minute check, the mixture is nothing changed and not ready to set. Next 10 minute check, the mixture is set, but remain very little of water on the top of the mould. Finally, 25 minute check, the mixture is completely set "Hard mould", no water. | Very bad mixture mould, very thin mixture, 45 minute the mixture set and without remain water on the top of the mould. | The mixture need to be improved, refer to the next experiment Gm20. |

Table A2. 20

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm20 | 0.5 kg | 60% F. c. p. 0.3 kg-300g = 480 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>20% Flint 0.1 kg-100g = 140 Millilitres<br>100% 0.5 kg-500g 760 Millilitres<br><br>F.c.p = 300x1.6 = 480 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>Flint = 100x1.4 = 140 Millilitres<br><br>F.c.p = 480/760x100 = 1200/19 = 63.2%<br>F. ctb. p = 140/760x100 = 350/19 = 18.4%<br>Flint = 140/760x100 = 350/19 = 18.4%<br>100% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture is good, creamy, thick and opaque and pour in the roller zinc. Next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Good mixture mould, 10 minute the mixture is set and no water on the top of the mould. | Perfect mixture mould and recommended, to be tested in the experiment II. Good for slumping and fusing glass mould only. |

Table A2. 21

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm21 | 0.5 kg | 30% F. c. p. 0.15 kg-150g = 240 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>15% Flint 0.07 kg- 75g = 105 Millilitres<br>15% Silv. Sd. 0.075 kg- 75g = 60 Millilitres<br>20% G. old m. 0.1 kg-100g =200 Millilitres<br>100% 0.5 kg-500g 745 Millilitres<br>F.c.p = 150x1.6 = 240 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitre<br>Flint = 75x1.4 = 105 Millilitres<br>Silv. sd. = 75x0.8 = 60 Millilitre<br>G. old. M = 100x2 = 200 Millilitres<br>F,c,p =240/745x100 = 4800/149 = 32.2%<br>F. ctb. p = 140/745x100 = 2800/149 = 18.8%<br>Flint = 105/745x100 = 2100/149 = 14.1%<br>Silv. sd. = 60/745x100 = 1200/149 = 8.1%<br>G. old m. = 200/745x100 = 4100/149 = 26.8%<br>!00% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is bad, too thin, pour in the roller zinc. Next 10 minute check, the mixture is ready to set. Next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Very bad mixture mould, too thin mixture. Although 20 minute the mixture set and no water on the top of the mould. | The mixture need to be improved, refer to the next experiment Gm22. |

Table A2. 22

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm22 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>10% F. ctb. p. 0.05 kg- 50g = 70 Millilitres<br>10% Flint 0.05 kg- 50g = 70 Millilitres<br>10% Silv. Sd. 0.05 kg- 50g = 40 Millilitres<br>30% G. old m. 0.15 kg-150g = 300 Millilitres<br>100% 0.5 kg-500g 800 Millilitres<br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 50x1.4 = 70 Millilitres<br>Flint = 50x1.4 = 70 Millilitres<br>Silv. sd. = 50x0.8 = 40 Millilitres<br>G. old m. = 150x2 = 300 Millilitres<br>F.c.p = 320/800x100 = 40/1 = 40%<br>F. ctb. p = 70/800x100 = 35/4 = 8.8%<br>Flint = 70/800x100 = 35/4 = 8.8%<br>Silv. sd. = 40/800x100 = 5/1 = 5%<br>G. old m. = 300/800x100 = 75/2 = 37.5%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, creamy, thick and opaque, pour in the roller zinc. Next 5 minute check, the mixture is set and no water on the top of the mould. Finally, next 5 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Very good mixture mould, creamy thick and opaque. 10 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Good for glass investment casting mould. |

Table A2. 23

| Code No. | Mould Weight | Material Mixture Weight/ grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm23 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>25% F. ctb. p. 0.125 kg-125g = 175 Millilitres<br>20% G. old m. 0.1 kg-100g = 200 Millilitres<br>10% C. clay 0.05 kg- 50g = 140 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>100% 0.5 kg-500g 1085 Millilitres<br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 125x1.4 = 175 Millilitres<br>G. old m. = 100x2 = 200 Millilitres<br>C. clay = 50x2.8 = 140 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br>F.c.p = 320/1085x100 = 6400/217 = 29.5 %<br>F. ctb. p = 175/1085x100 = 3500/217 = 16.1%<br>G. old m. = 200/1085x100 = 4000/217 = 18.4%<br>C. clay = 140/1085x100 = 2800/217 = 12.9%<br>Vermicul. = 250/1085x100 = 5000/217 = 23%<br>99.9% | 0.4 Lit. 400 Ml. | 10 minute stir, the mixture is thick, pour in the roller zinc. Next 10 minute check, the mixture is completely set "Very Hard mould", no water on the top of the mould. | Very bad mixture mould, very thick mixture. Although 10 minute the mixture set and no water on the top of the mould. | The mixture need to be improved, refer to the next experiment Gm24. |

Table A2. 24

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm24 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>20% F. ctb. p. 0.15 kg-150g = 210 Millilitres<br>10% G. old m. 0.05 kg- 50g = 100 Millilitres<br>10% C. clay 0.05 kg- 50g = 140 Millilitres<br>10% Vermicul. 0.05 kg- 50g = 500 Millilitres<br>100% 0.5 kg-500g 1270 Millilitres<br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 150x1.4 = 210 Millilitres<br>G. old m. = 50x2 = 100 Millilitres<br>C. clay = 50x2.8 = 140 Millilitres<br>Vermicul. = 50x10 = 500 Millilitres<br>F.c.p = 320/1270x100 = 3200/127 = 25.2%<br>F. ctb.p = 210/1270x100 = 2100/127 = 16 5%<br>G. old m. = 100/1270x100 = 1000/127 = 7.9%<br>C.clay = 140/1270x100 = 1400/127 = 11%<br>Vermicul. = 500/1270x100 = 5000/127 = 39.4% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is bad, too thick mixture, pour in the roller zinc. Next 10minute check, the mixture is set "Hard mould", no water on the top of the mould. | Very bad mixture mould, too thick mixture, although 10 minute the mixture set and no water on the top of the mould. | The mixture need to be improved, refer to the next experiment Gm25. |

Table A2. 25

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm25 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>25% F. ctb. p. 0.125 kg-125g = 175 Millilitres<br>15% G. old m. 0.075 kg- 75g = 150 Millilitres<br>5% C. clay 0.025 kg- 25g = 70 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>100% 0.5 kg-500g 1045 Millilitres<br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb p = 125x1.4 = 175 Millilitres<br>G. old m. = 75x2 = 150 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br>F.c.p =400/1045x100 = 8000/209 = 38.3%<br>F. ctb.p = 175/1045x100 = 3500/209 = 16.7%<br>G. old m. = 150/1045x100 = 3000/209 = 14.4%<br>C. clay = 70/1045x100 = 1400/209 = 6.7%<br>Vermicul. = 250/1045x100 = 5000/209 = 23.9%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, thick and opaque, pour in the roller zinc. Next 10 minute check, the mixture is set and no water on the top of the mould. Next 5 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Good mixture mould, thick and opaque, 20 minute the mixture set and no water on the top of the mould. Better than Gm23 and Gm24 mixture. | The mixture need to be improved, refer to the next experiment Gm26. The mixture can be used only for outer layer mould, which aim to strengthen the mould. |

Table A2. 26

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm26 | 0.5 kg | 55% F. c. p. 0.275 kg-275g = 440 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>15% G. old m. 0.075 kg- 75g = 150 Millilitres<br>5% C. clay 0.025 kg- 25g = 70 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>100% 0.5 kg-500g 1050 Millilitres<br>F.c.p = 275x1.6 = 440 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>G. old m. =75x2 = 150 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br>F.c.p = 440/1050x100 = 880/21 = 41.9%<br>F. ctb.p = 140/1050x100 = 40/3 = 13.3%<br>G. old m. =150/1050x100 = 100/7 = 14.3%<br>C. clay = 70/1050x100 = 20/3 = 6.7%<br>Vermicul. = 250/1050x100 = 500/21 = 23.8% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, thick and opaque, pour in the roller zinc. Next 10 minute stir, the mixture is completely set and no water on the top of the mould. | Good mixture mould, thick and opaque. 15 minute set mould, no water on the top of the mould. Better than the Gm23, Gm24 and Gm25 mixture. | The mixture need to be improved, refer to the next experiment Gm27. The mixture can be used only for outer layer, which aim to strengthen the mould. |

Table A2. 27

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm27 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>30% F. ctb. p. 0.15 kg-150g = 210 Millilitres<br>20% G. old m. 0.1 kg-100g = 200 Millilitres<br>5% C. clay 0.025 kg- 25g = 70 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>100% 0.5 kg-500g 1050 Millilitres<br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 150x1.4 = 210 Millilitres<br>G. old m. = 100x2 = 200 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>Vermicul. = 25x10 = 200 Millilitres<br>F.c.p = 320/1050x100 = 640/21 = 30.5%<br>F. ctb. p = 210/1050x100 = 420/21 = 20%<br>G. old m. = 200/1050x100 = 400/21 = 19%<br>C. clay = 70/1050x100 = 140/21 = 6.7%<br>Vermicul. = 250/1050x100 = 500/21 = 23.8%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is good, thick and opaque, pour in the roller zinc. Next 10 minute check, the mixture is set and no water on the top of the mould. Next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Good mixture mould, thick and opaque. 20 minute the mixture set and no water on the top of the mould. Better than the Gm23,Gm 24,Gm25 and Gm26 mixture. | The mixture need to be improved, refer to the next experiment Gm28. The mixture can be used only for outer layer, which the aim to strengthen the mould. |

Table A2. 28

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c,c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm28 | 0.5 kg | 30% F. c. p. 0.15 kg-150g = 240 Millilitres<br>30% F. ctb. p. 0.15 kg-150g = 210 Millilitres<br>30% G. old m. 0.15 kg-150g = 300 Millilitres<br>5% C. clay 0.025 kg- 25g = 70 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>100% 0.5 kg-500g 1070 Millilitres<br>F.c.p =150x1.6 = 240 Millilitres<br>F. ctb. p = 150x1.4 = 210 Millilitres<br>G. old m. = 150x2 = 300 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br>F.c.p = 240/1070x100 = 2400/107 = 22.4%<br>F. ctb. p = 210/1070x100 = 2100/107 = 19.6%<br>G. old m. = 300/1070x100 = 3000/107 = 28%<br>C. clay = 70/1070x100 = 700/107 = 6.5%<br>Vermicul. = 250/1070x100 = 2500/107 = 23.4% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is bad, too thick, pour in the roller zinc. Next 15 minute check, the mixture is going to set, another 5 minute check, the mixture is remained the same. Finally, next 25 minute, the mixture is completely set "Hard mould", no water on the top of the mould. | Very bad mixture mould, even worst than the Gm23,Gm 24, Gm25, Gm26 and Gm27 mixture. | The mixture need to be improved, refer to the next experiment Gm29. |

Table A2. 29

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm29 | 0.5 kg | 60% F. c. p. 0.3 kg-300g = 480 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>10% G. old m. 0.05 kg- 50g = 100 Millilitres<br>5% C . clay 0.025 kg-25g = 70 Millilitres<br>5% Vermicul. 0.025 kg-25g = 250 Millilitres<br>100% 0.5 kg-500g 1040 Millilitres<br>F.c.p = 300x1.6 = 480 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>G. old m. = 50x2 = 100 Millilitres<br>C, clay = 25x2.8 = 70 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br>F.c.p = 480/1040x100 = 1200/26 = 46.2%<br>F. ctb. p = 140/1040x100 = 350/26 = 13.5%<br>G. old m. = 100/1040x100 = 250/26 = 9.6%<br>C. clay = 70/1040x100 = 175/26 = 6.7%<br>Vermicul. = 250/1040x100 = 625/26 = 24%<br>100% | 0.4 Lit. 400 Ml | 5 minute stir, the mixture is very good, creamy, thick and opaque, pour in the roller zinc. Next 10 check, the mixture is set and no water on the top of the mould. Finally, the next 5 minute check, the mixture is completely set "Hard mould, no water on the top of the mould. | Very good mixture mould, creamy, thick and opaque. 15 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Good for the glass investment casting mould. |

Table A2. 30

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm30 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>25% F. ctb. p. 0.125 kg-125g = 175 Millilitres<br>30% G. old m. 0.15 kg-150g = 300 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>100% 0.5 kg-500g 1045 Millilitres<br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 125x1.4 = 175 Millilitres<br>G. old m. = 150x2 = 300 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br>F.c.p = 320/1045x100 = 6400/209 = 30.6%<br>F. ctb. p = 175/1045x100 = 3500/209 = 16.7%<br>G. old m. = 300/1045x100 = 6000/209 = 28.7%<br>Vermicul. = 250/1045x100 = 5000/209 = 23.9%<br>99.9% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is slightly thick and opaque, pour in the roller zinc. Next 10 minute check, the mixture is going to set, the next 10 minute check, the mixture is set but soft mould, no water on the top of the mould. Finally, the next 5 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | The mixture is slightly thick and opaque and 25 minute the mixture set, no water on the top of the mould. | The mixture need to be improved, refer to the next experiment Gm31. |

Table A2. 31

| Code No. | Mould Weight | Material Mixture<br>Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm31 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>25% F. ctb. p. 0.125 kg-125g = 175 Millilitres<br>20% G. old m. 0.1 kg-100g = 200 Millilitres<br>5% Vermicul.0.025 kg- 25g = 250 Millilitres<br>100% 0.5 kg-500g<br>1025 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 125x1.4 = 175 Millilitres<br>G. old m. = 100x2 = 200 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br><br>F.c.p = 400/1025x100 = 1600/41 = 39%<br>F. ctb. p = 175/1025x100 = 700/41 = 17.1%<br>G. old m. = 200/1025x100 = 800/41 = 19.5%<br>Vermicul. = 250/1025x100 = 1000/41 = 24.4%<br><br>100% | 0.4 Lit.<br>400 Ml. | 5 minute stir, the mixture is really good, creamy, thick and opaque, pour in the roller zinc. Next 15 check, the mixture is set, but soft mould and no water on the top of the mould. Finally, the next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Very Good mixture mould, creamy, thick and opaque. 25 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Good for the glass investment casting mould. |

Table A2. 32

| Code No. | Mould Weight | Material Mixture<br>Weight/ Grams Volume/ Millilitres (c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm32 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>25% F. ctb. p. 0.125 kg-125g = 175 Millilitres<br>10% Silv. sd. 0.05 kg- 50g = 40 Millilitres<br>25% G. old m. 0.125 kg-125g = 250 Millilitres<br>100% 0.5 kg-500g<br>785 Millilitres<br><br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 125x1.4 = 175 Millilitres<br>Silv. sd. = 50x0.8 = 40 Millilitres<br>G. old m. = 125x2 = 250 Millilitres<br><br>F.c.p = 320/785x100 = 6400/157 = 40.8%<br>F. ctb. p = 175/785x100 = 3500/157 = 22.3%<br>Silv. sd. = 40/785x100 = 800/157 = 5.1%<br>G. old m. = 250/785x100 = 5000/157 = 31.8%<br>100% | 0.4 Lit.<br>400 Ml. | 5 minute stir, the mixture is very good, creamy, thick and opaque, pour in the roller zinc. Next 15 minute check, the mixture is going to set. Finally, the next 10 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Very good mixture mould, creamy, thick and opaque. 25 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Good for the glass investment casting mould. |

Table A2. 33

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm33 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>15% F. ctb. p. 0.075 kg- 75g = 105 Millilitres<br>15% Flint 0.075 kg- 75g = 105 Millilitres<br>5% C. clay 0.025 kg- 25g = 70 Millilitres<br>15% G. old m.0.075 kg- 75g = 150 Millilitres<br>10% C. ctb. p. 0.05 kg- 50g = 80 Millilitres<br>100% 0.5 kg- 500g 830 Millilitres<br><br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 75x1.4 = 105 Millilitres<br>Flint = 105x1.4 = 105 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>G. old m. = 75x2 =150 Millilitres<br>C. ctb. p = 50x1.6 = 80 Millilitres<br><br>F.c.p = 320/830x100 = 3200/83 = 38.6%<br>F. ctb. p = 105/830x100 = 1050/83 = 12.7%<br>Flint = 105/830x100 = 1050/83 = 12.7%<br>C. clay = 70/830x100 = 700/83 = 8.4%<br>G. old m. = 150/830x100= 1500/83 = 18%<br>C. ctb. p = 800/830x100 = 800/83 = 9.6%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is very good, creamy, thick and opaque, pour in the roller zinc. Next 20 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Very good mixture mould, creamy, thick and opaque. 20 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Good for the glass investment casting mould. |

Table A2. 34

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm34 | 0.5 kg | 40% F. c. p. 0.2 kg-200g = 320 Millilitres<br>10% F. ctb. p. 0.05 kg- 50g = 70 Millilitres<br>40% Flint 0.2 kg-200g = 280 Millilitres<br>5% C. clay 0.025 kg-25g = 70 Millilitres<br>5% G. fibre 0.025 kg-25g = 100 Millilitres<br>100% 0.5 kg-500g 840 Millilitres<br>F.c.p = 200x1.6 = 320 Millilitres<br>F. ctb. p = 50x1.4 = 70 Millilitres<br>Flint = 200x1.4 = 280 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>G. fibre = 25x4 = 100 Millilitres<br>F.c.p = 320/840x100 = 1600/42 = 38.1%<br>F. ctb. p = 70/840x100 = 350/42 = 8.3%<br>Flint = 280/840x100 = 1400/42 = 33.3%<br>C. clay = 70/840x100 = 350/42 = 8.3%<br>G. fibre = 100/840x100 = 500/42 = 11.9%<br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is very good, creamy, thick and opaque, pour in the roller zinc. Next 15 minute check, the mixture is mould and no water on the top of the mould. Finally, the next 10 minute check, the mixture is completely set " Hard mould", no water on the top of the mould. | Very good mixture mould, creamy, thick and opaque. 25 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Good for the glass investment casting mould. |

Table A2. 35

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm35 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>5% Silv. sd. 0.025 kg- 25g = 20 Millilitres<br>20% G. old m. 0.1 kg-100g = 200 Millilitres<br>5% Vermicul. 0.025 kg- 25g = 250 Millilitres<br>100% 0.5 kg-500g 1010 Millilitres<br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>Silv. sd. = 25x0.8 = 20 Millilitres<br>G. old m. = 100x2 = 200 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br>F.c.p = 400/1010x100 = 4000/101 = 39.6%<br>F. ctb. p = 140/1010x100 = 1400/101 = 13.9%<br>Silv. sd. = 20/1010x100 = 200/101 = 1.9%<br>G. old m.= 200/1010x100 = 2000/101= 19.8%<br>Vermicul.= 250/1010x100= 2500/101= 24.7% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is very good, creamy, thick and opaque, pour in the roller zinc. Next 15 minute check, the mixture is set and no water on the top of the mould. Finally, the next 5 minute check, the mixture is completely set "Hard mould" and no water on the top of the mould. | Very good mixture mould, creamy, thick and opaque. 20 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Good for the glass investment casting mould. |

Table A2. 36

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm36 | 0.5 kg | 30% F. c. p. 0.15 kg-150g = 240 Millilitres<br>30% F, ctb. p. 0.15 kg-150g = 210 Millilitres<br>15% Flint 0.075 kg-75g = 105 Millilitres<br>15% G. old m. 0.075 kg-75g = 150 Millilitres<br>5% Vermicul. 0.025 kg-25g = 250 Millilitres<br>5% C. clay 0.025 kg-25g = 70 Millilitres<br>100% 0.5 kg-500g 1025 Millilitres<br><br>F.c.p = 150x1.6 = 240 Millilitres<br>F. ctb. p = 150x1.4 = 210 Millilitres<br>Flint = 75x1.4 = 105 Millilitres<br>G. old m. = 75x2 = 150 Millilitres<br>Vermicul. = 25x10 = 250 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br><br>F.c.p = 240/1025x100 = 960/41 = 23.4%<br>F. ctb. p = 210/1025x100 = 840/41 = 20.5%<br>Flint = 105/1025x100 = 420/41 = 10.2%<br>G. old m. = 150/1025x100 = 600/41 = 14.6%<br>Vermicul. = 250/1025x100 = 1000/41 = 24.4%<br>C. clay = 70/1025x100 = 280/41 = 6.8%<br>99.9% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is very good, creamy, thick and opaque, pour in the roller zinc. Next 15 minute check, the mixture is set but soft and no water on the top of the mould. Finally, the next 5 minute check, the mixture is completely set "Hard mould", no water on the top of the mould. | Very good mixture mould, creamy thick and opaque. 20 minute the mixture is set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Highly recommended for glass investment casting mould. |

Table A2. 37

| Code No. | Mould Weight | Material Mixture Weight/ Grams Volume/ Millilitres ( c.c ) | Water | Material Mixture Activities | Result | Recommended |
|---|---|---|---|---|---|---|
| Gm37 | 0.5 kg | 50% F. c. p. 0.25 kg-250g = 400 Millilitres<br>20% F. ctb. p. 0.1 kg-100g = 140 Millilitres<br>20% Flint 0.1 kg-100g = 140 Millilitres<br>5% C. clay 0.025 kg-25g = 70 Millilitres<br>5% G. old m. 0.025 kg-25g = 50 Millilitres<br>100% 0.5 kg-500g 800 Millilitres<br><br>F.c.p = 250x1.6 = 400 Millilitres<br>F. ctb. p = 100x1.4 = 140 Millilitres<br>Flint = 100x1.4 = 140 Millilitres<br>C. clay = 25x2.8 = 70 Millilitres<br>G. old m. = 25x2 = 50 Millilitres<br><br>F.c.p = 400/800x100 = 50/1 = 50%<br>F. ctb. p = 140/800x100 = 35/2 = 17.5%<br>Flint = 140/800x100 = 35/2 = 17.5%<br>C. clay = 70/800x100 = 70/8 = 8.8%<br>G. old m. = 50/800x100 = 50/8 = 6.2%<br><br>100% | 0.4 Lit. 400 Ml. | 5 minute stir, the mixture is very good, creamy, thick and opaque, pour in the roller zinc. Next 20 minute check, the mixture is completely set "Hard mould" and no water on the top of the mould. | Very good mixture mould, creamy thick and opaque. 20 minute the mixture set and no water on the top of the mould. | Perfect mixture mould and recommended to be tested in the experiment II. Highly recommended for glass investment casting mould |

# Appendix: 3

## Experiment I : Slurry Technique. Conversion from Weight to Volume

| Materials | Weight / Grams | Volume / Millilitres ( c.c ) |
|---|---|---|
| 1. Fine casting plaster | 50 Grams | 80 Millilitres |
| | 25 Grams | 40 Millilitres |
| | 1 Gram | 1.6 Millilitres |
| 2. Fine cuttlefish bone powder | 50 Grams | 70 Millilitres |
| | 25 Grams | 35 Millilitres |
| | 1 Gram | 1.4 Millilitres |
| 3. Coarse cuttlefish bone | 50 Grams | 80 Millilitres |
| | 25 Grams | 40 Millilitres |
| | 1 Gram | 1.6 Millilitres |
| 4. Fine building sand | 50 Grams | 40 Millilitres |
| | 25 Grams | 20 Millilitres |
| | 1 Gram | 0.8 Millilitre |
| 5. China clay | 50 Grams | 140 Millilitres |
| | 25 Grams | 70 Millilitres |
| | 1 Gram | 2.8 Millilitres |
| 6. Fine grog | 50 Grams | 40 Millilitres |
| | 25 Grams | 20 Millilitres |
| | 1 Gram | 0.8 Millilitres |
| 7. Coarse grog | 50 Grams | 40 Millilitres |
| | 25 Grams | 20 Millilitres |
| | 1 Gram | 0.8 Millilitres |
| 8. Molochite | 50 Grams | 50 Millilitres |
| | 25 Grams | 25 Millilitres |
| | 1 Gram | 1 Millilitre |
| 9. Silver sand | 50 Grams | 40 Millilitres |
| | 25 Grams | 20 Millilitres |
| | 1 Gram | 0.8 Millilitre |
| 10. Flint | 50 Grams | 70 Millilitres |
| | 25 Grams | 35 Millilitres |
| | 1 Gram | 1.4 Millilitres |
| 11. Vermiculate | 50 Grams | 500 Millilitres |
| | 25 Grams | 250 Millilitres |
| | 1 Gram | 10 Millilitres |
| 12. Glass old mould | 50 Grams | 100 Millilitres |
| | 25 Grams | 50 Millilitres |
| | 1 Gram | 2 Millilitres |
| 13. Glass Fibre | 50 Grams | 200 Millilitres |
| | 25 Grams | 100 Millilitres |
| | 1 Gram | 4 Millilitres |